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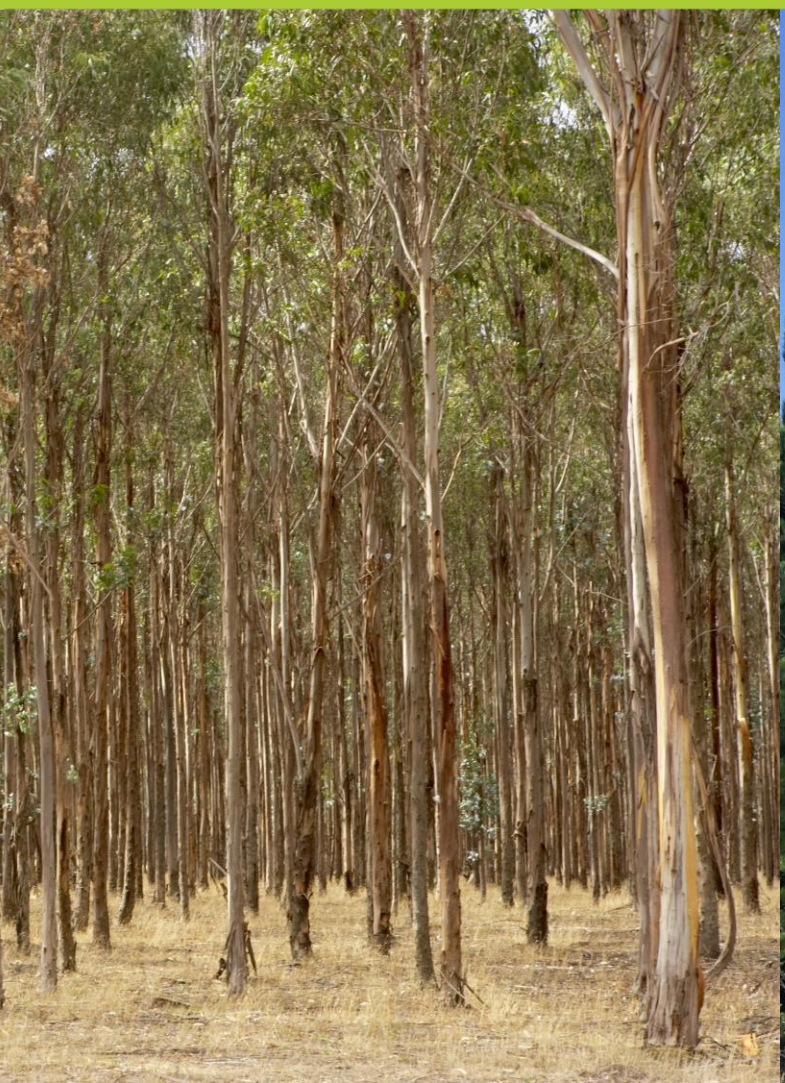
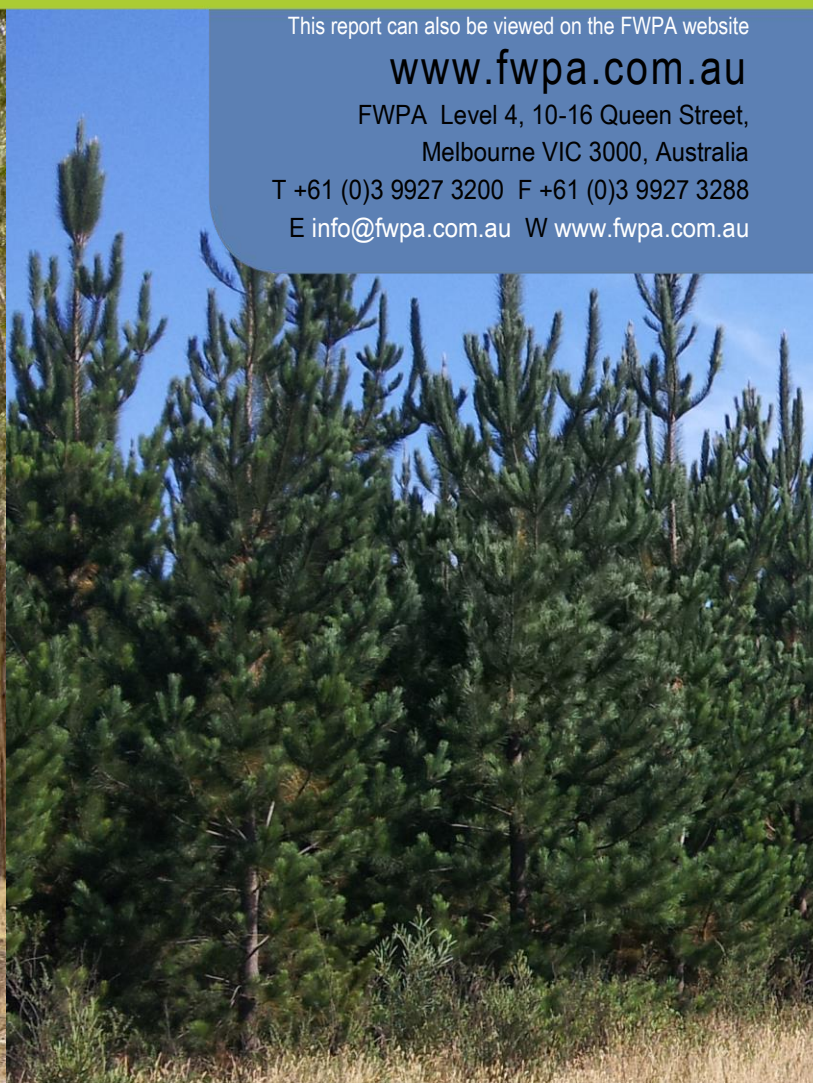
The Forest Productivity Optimisation System – A decision support tool for enhancing the management of planted forests in southern Australia under changing climate





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The Forest Productivity Optimisation System – A decision support tool for enhancing the management of planted forests in southern Australia under changing climate

Prepared for

Forest & Wood Products Australia

by

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Executive Summary

This project developed the "Forest Productivity Optimisation System," a web-based decision support system to help plantation managers understand the impacts on plantation productivity and profitability of changing climate and different management, sites and species choices. FPOS is based on the 'Blue gum Productivity Optimisation System', which was a product of the Forestry CRC. FPOS is a major enhancement to BPOS, extending it in several key ways, including: (1) allowing the user to explore many more climatic zones, (2) modelling up to 5 species instead of 1, (3) accounting for solid wood as well as pulpwood products. The 3 commonly used species in southern Australia were included in FPOS (*E. nitens*, *E. globulus* and *P. radiata*), as well as *P. pinaster* and *E. smithii* that are considered to be better adapted to the likely increases in temperature and decreases in rainfall. The engine behind FPOS is a live version of CABALA, connected to a database of outputs so that CABALA does not need to be re-run twice for the same scenario. This report: (1) describes the detailed physiological studies into *E. smithii* that we conducted to be able to include it in the DSS, the climatic modelling and model choice, and the CABALA parameterisation, and (2) includes the user manual for FPOS, describing each part of the system and the assumptions and underlying models that are used to produce the relevant output.

The FPOS system should be regarded as a synthesis of the best currently available knowledge, but there is still significant scope for further improvement of both the interface and underlying models. The benefits of the FPOS system would be maximised by investing time in the training of industry staff in its use. CRC Forestry members and FWPA levy payers have free access to the system, and should enquire with the developers about arranging for a username and password. The system login page is at https://www.crcforestrytools.com.au/fpos/login.aspx.

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Introduction

Plantation managers need to make management decisions based on information from a range of sources. New information arising from research can sometimes be difficult to assimilate into an overall understanding of its importance to productivity and profitability, especially in conditions of uncertainty surrounding new management and new soil types, or changing climate and water availability. This project developed the 'Forest Productivity Optimisation System' tool to help managers integrate current knowledge with outcomes of new research. The FPOS tool also allows managers to explore the potential for changing species to adapt to more marginal areas of the estate, and/or under changing climate. As well as the 3 core species used in most of the estate of southern Australia (*E. nitens*, *E. globulus* and *P. radiata*), *E. smithii* and *P. pinaster* are now included in the system as the two species that show the most promise for adaptation to drier and hotter conditions to demonstrate their potential at different site types or under changing climate.

The FPOS DSS has built on the Blue Gum Productivity Optimisation System (BPOS) version 2, which was developed by the CRC Forestry. BPOS v2.0 was designed to assist *E. globulus* growers with making management decisions, and through this project we have expanded its capabilities so that FPOS has application to both softwood and hardwood growers. It allows managers to explore different product options across the range of site types within the current estate, and alternative species.

The process-based model, CABALA, is the 'engine' that drives FPOS, but the DSS framework helps to (1) simplify the user's interaction with CABALA, and (2) allows for incorporation of information that cannot be currently or realistically captured in process-level models. It also helps people to migrate to CABALA for answers to more specific questions that they have for any given site, climate or management option.

The aims of this project were to (1) understand the physiological differences between *E. globulus* and *E. smithii* that may make *E. smithii* better adapted to the hotter and drier conditions that are predicted to occur in many of the plantation growing regions, (2) explore the range of down-scaled global circulation model predictions to understand the best, worst and most likely outcomes for future climate in each of the climatic regions that we focussed on, (3) calibrate and/or validate the CABALA model for the existing and new species across the range of sites that were used in the DSS, and (4) develop the FPOS system to integrate existing and new knowledge and present it in a form that was readily accessible by industry partners.

Methodology

This project was conducted through 4 main activities as follows

- CABALA model development and parameterisation for different species
- Climate model selection and application
- Detailed comparative studies into *E. smithii* and *E. globulus* in response to environment
- FPOS interface development.

The methodology for each of these is detailed below.

CABALA model development and parameterisation

CABALA (Battaglia et al. 2004) links the carbon, nitrogen and water balances in forests to predict productivity and water use. It is specifically targeted to silvicultural decision support and is underpinned by a large body of data describing the physiological responses of trees to both environmental and management factors. CABALA operates on a daily time step, simultaneously predicting fluxes of carbon, water and nitrogen within a forest stand. Mass of foliage, branch, stem, bark, coarse and fine roots are predicted. Carbon and nitrogen pools in the soil and litter layers are updated daily and vary according the balance between additions from residues (and atmospheric deposition in the case of nitrogen) and losses from decomposition. A more detailed description of CABALA is available in Battaglia et al. (2004).

There are limitations in using CABALA to predict potential growth rates. CABALA does not account for nutrient limitations other than nitrogen. For a site where phosphorus or other nutrients are limiting, CABALA will generally overestimate rates of growth.

There have been recent updates to the model which are listed below (more detail can be found in Battaglia 2012):

1. The Farquhar model of photosynthesis is now incorporated into CABALA, and improves the temperature interactions with elevated CO_2.

2. Effects of elevated CO_2 on water-use efficiency are now better predicted with the incorporation of the Farquhar photosynthesis model, combined with the Ball-Berry model already built into CABALA.

3. Incorporation of high temperature effects on leaf membranes and photosynthesis**.** While high temperature effects were already integrated into CABALA, this did not allow for evaporative cooling, which is an important response protecting leaves from death under high temperature conditions. This has now been rectified.

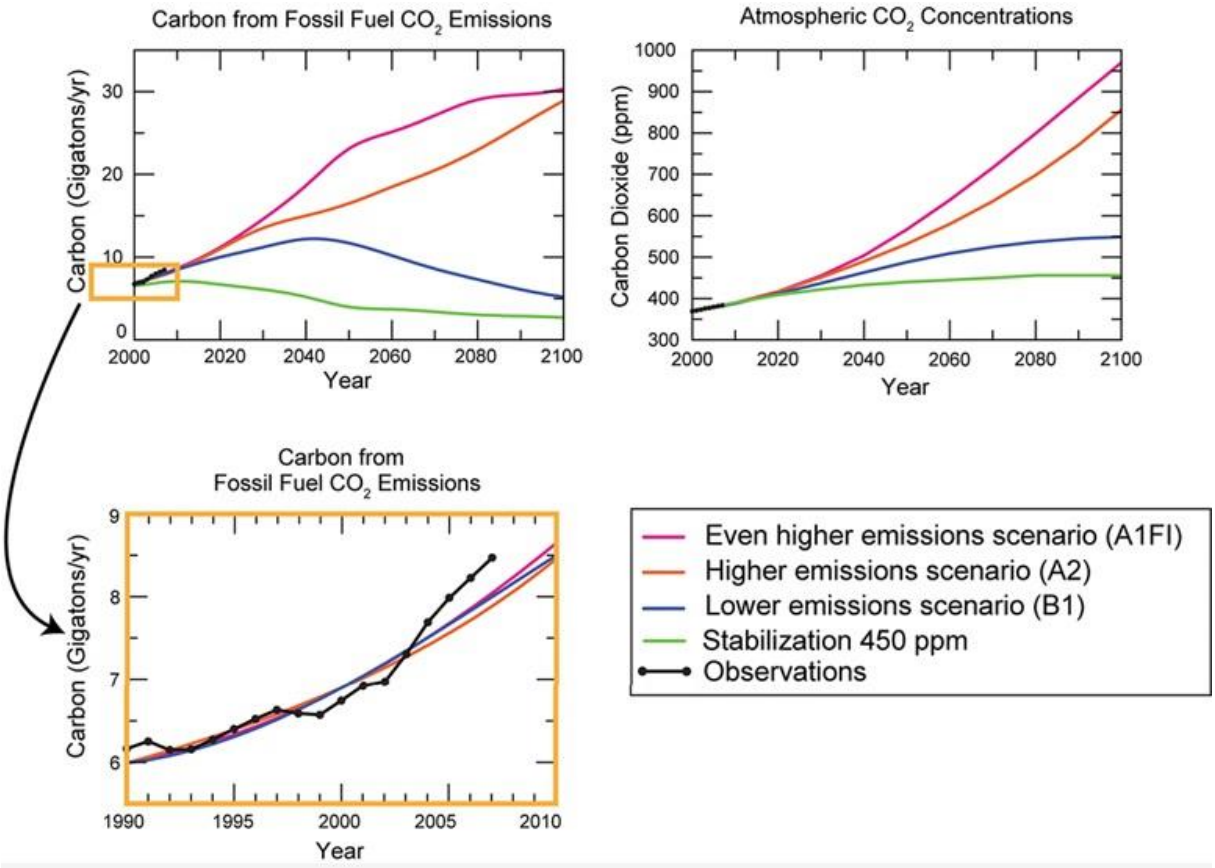
4. Inclusion of the SPA framework for predicting hydraulic gradients in trees provides the basis for predicting the diurnal course of tree water stress (see White et al. 2011 for summary information).

Combined, these changes are anticipated to improve model predictions of the effects of elevated CO_2, and climate change more generally, on plantation productivity.

Climate model selection and application

Appropriate sampling of uncertainty is a fundamental part of assessing the impacts of future climates on the growth of production forests. Currently there are 24 global circulation models (23 from the Coupled Model Intercomparison Project (CMIP3) plus the CSIRO-Mk3.5 model) that are well tested for Australia and readily available. We also used the A2 emission scenario (see Fig. 1), which assumes continued rapid economic growth and increasing population with minimal global migration to a low CO_2 emissions economy. Note that current global emissions are above this scenario (Fig. 1).

Fig. 1 – Summary of emissions scenarios (we have used the A2 scenario in this project). Source: USGCRP (2009)



There can be substantial differences between the future climates predicted by the models and it often unviable for end-users with limited resources to run all 24 models to cover the range in potential futures. While it may be tempting to use a single "mid-range" model, this overlooks other out-lying and potentially important future climates (Clarke 2011) and does not provide enough information to managers to allow for the risk of worst case scenarios or potential opportunities with the best case. Selecting a small number of models should be based on criteria that limit bias and are as objective as possible (Clarke 2011).

The Climate Futures Framework (Clarke 2001) overcomes these limitations by classifying the projected changes from the full suite of climate models into classes defined by two climate variables – usually annual mean temperature and rainfall. Relative likelihoods are assigned to each class or climate future based on the number of climate models that fall within that category. For example, if 12 of 24 models fall into the "Warmer – Drier" climate future, it is given a relative likelihood of 50% (Clarke 2011). A subset of models can be selected to represent the range in climate futures. In this instance we have selected a best (ie. highest rainfall, least temperature rise), worst (ie. the lowest rainfall and highest temperature rise) and

most likely future climate (ie. the temperature and rainfall change that is predicted by the majority of the models). This allows the user to focus on the output from the most likely model (where the future climate predictions converge), while the best and worst case can provide bounds around the uncertainty of those predictions. The model choices for each climatic zone are detailed in Appendix 1.

Comparative physiology of *E. smithii* and *E. globulus*

To understand more about the potential for *E. smithii* as an alternative to *E. globulus* in hotter and drier conditions we established an experiment in an existing 2nd rotation plantation in the Shuttleworth plantation (managed by WA Plantation Resources) which had *E. smithii* and *E. globulus* growing adjacent to each other. We measured the growth and physiological responses of the 2 species to differing environmental stimuli over a period of nearly 3 years. The location of the Shuttleworth plantation is shown in Fig. 2, and it has an average annual rainfall of 659 mm, and evaporation of 1108 mm (30-year average to 2012, derived from the SILO data drill service, Jeffrey et. al. 2001). Average monthly climatic data for the Shuttleworth site is shown in Table 1.

Fig. 2 – map showing the location of the Shuttleworth plantation

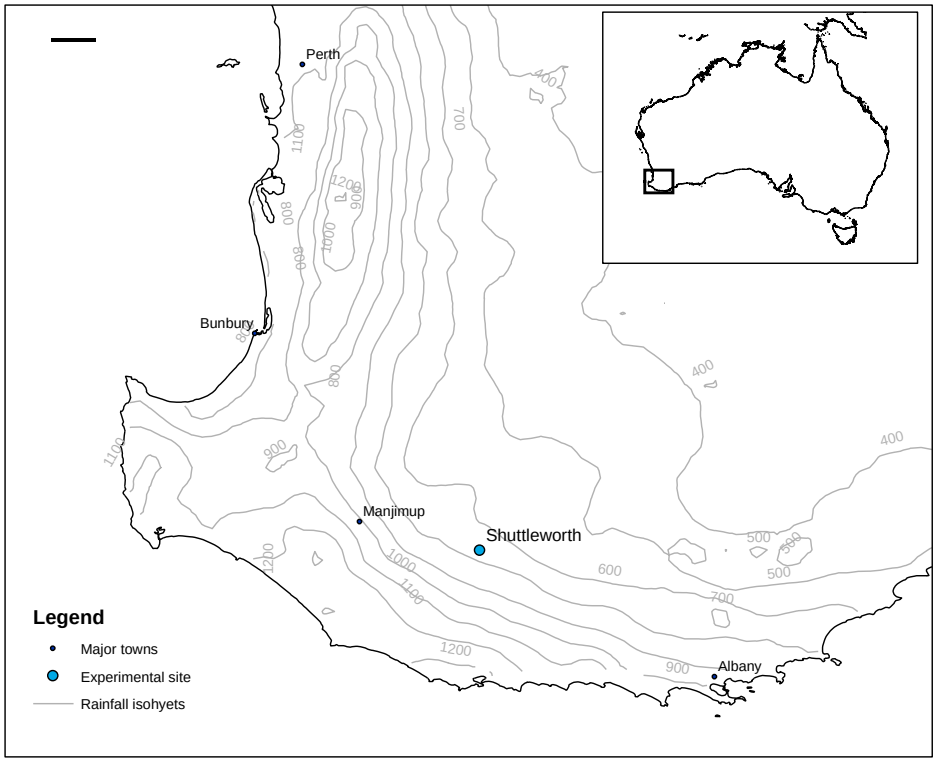
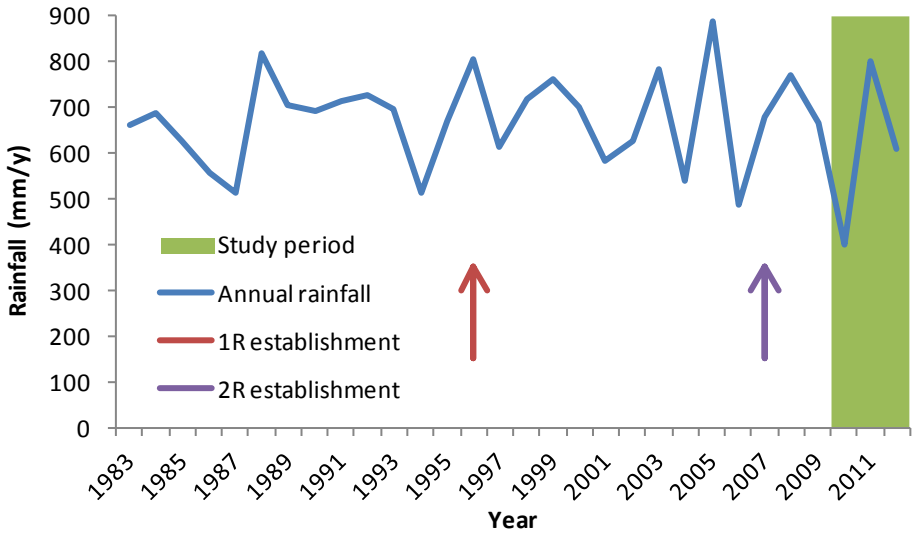


Table 1 – Selected average monthly climate data at the Shuttleworth site (30 years to 2012), derived from the SILO data drill service (Jeffrey et. al., 2001).

Month	Average daily temp. (°C)		Radiation	Rainfall	Rain days
	Maximum	Minimum	(MJ/m^2)	(mm)	
January	27.6	13.2	25.1	16.8	6.3
February	27.5	13.7	22.2	18.8	6.0
March	25.4	12.7	17.8	20.6	8.4
April	22.1	10.9	13.0	37.4	11.7
May	18.4	8.9	9.4	85.3	17.9
June	15.8	7.3	8.1	93.2	20.7
July	14.9	6.5	8.7	109.5	22.5
August	15.3	6.5	11.5	95.0	22.0
September	17.0	7.2	14.9	75.2	19.7
October	19.1	8.1	18.9	52.7	17.3
November	22.4	10.0	22.0	37.9	11.9
December	25.6	11.8	25.0	18.7	7.8

The study period started in 2010 when the 2nd rotation plantation was 3 years old. Fig. 3 shows the study period in relation to the annual rainfall and establishment of the first and second rotation plantations at the Shuttleworth site.

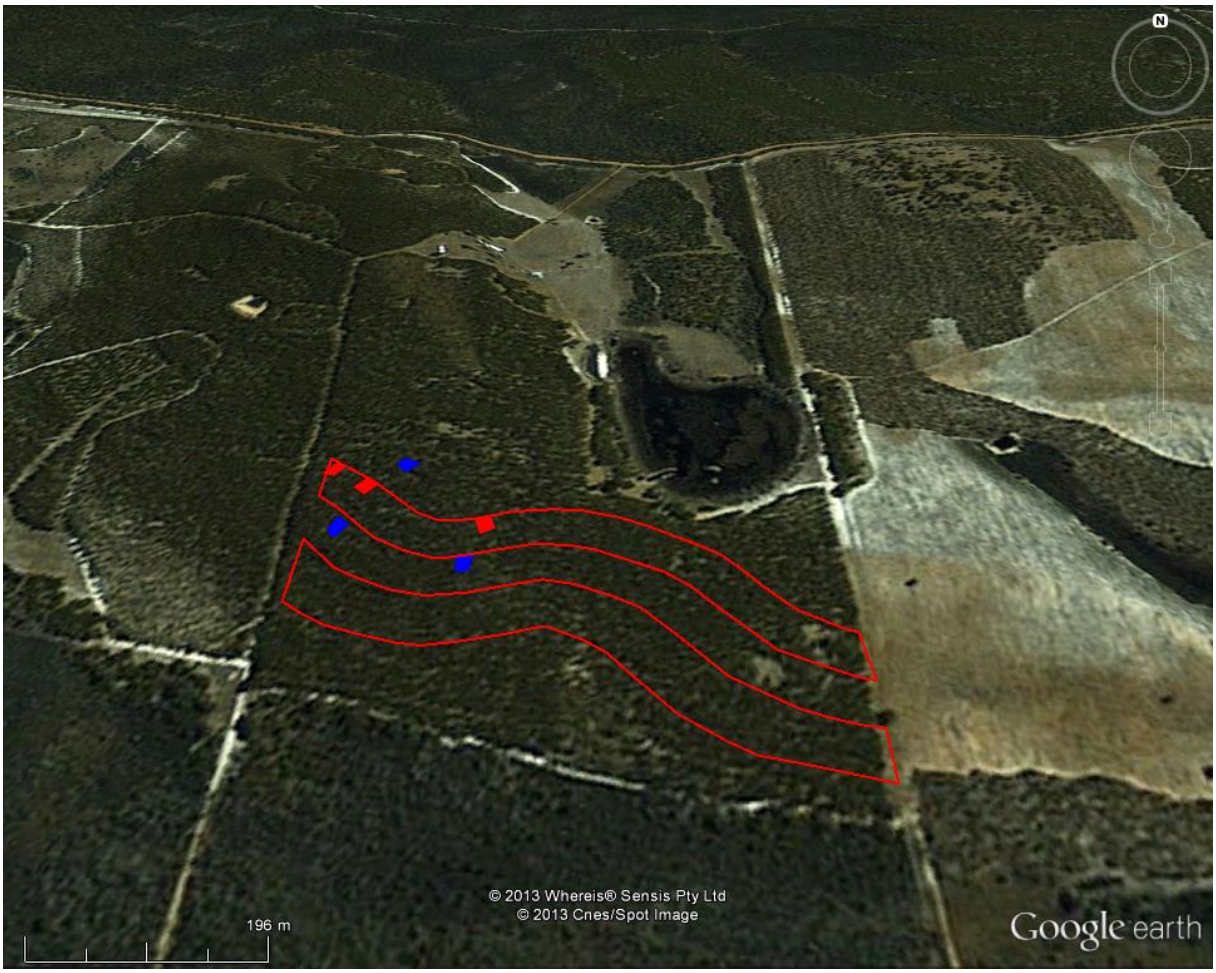
Fig. 3 – Annual rainfall for the 30 years from 1983-2012 at the Shuttleworth site, with the study period highlighted in green. The planting dates of the first and second rotations are highlighted with arrows.



Experimental plots

The Shuttleworth site had been planted with 2 wide belts (about 60 m wide and 700 m long) of *E. smithii*, amongst a large *E. globulus* 2nd rotation plantation (Fig. 4). The belts had been planted as part of an operational trial into the potential deployment of *E. smithii* on drought-prone sites. The lower (southern-most) belt was not used because it was close to the valley floor and may have been affected by salinity or presence of a hard pan. Measurement plots (20 x 20 m) were established in pairs, 20 m from the edge of the *E. smithii/E. globulus* interface.

Fig. 4 – Oblique image of the Shuttleworth plantation, showing locations of the *E. smithii* belts and the experimental plots. Surrounding plantation is *E. globulus*. Image copyright Google Earth. Note the location of the plots and *E. smithii* belts is approximate as the plot corners were measured with a standard GPS with an accuracy of around 20 m.



Measurements

To track the tree growth and water stress at the Shuttleworth site, we made the following measurements over 2.5 years (2010-2013):

- Tree growth was measured on every tree in each plot annually
- Dendrometers were installed to measure diameter on 4 trees per plot (representing 4 evenly distributed size classes) at 30 minute intervals.
- Soil characterisation and NMM tube installation was completed using deep drilling at the start of the experiment (1 hole/tube per plot).
- Diurnal leaf gas exchange was measured four-times per year, in seasonally wet and dry conditions (5 trees per plot, however not all plots were measured at each time due to time constraints)
- LAI was measured twice per year, during summer and winter
- Pre-dawn leaf water potential was measured approximately 4 times per year
- Soil moisture was measured with a neutron moisture meter approximately 4 times per year, after the NMM tube installation in early 2011

FPOS Interface development

The FPOS web interface was based on the original code for the BPOS interface. It is developed in Microsoft .NET 2.0, and interfaces with 2 Microsoft SQL Server databases. A

live version of CABALA is embedded into the system and is run on request of the user. The interface integrates all of the outputs from the other sections of this project, including the climate futures, CABALA development and parameterisation, and comparative physiology of *E. globulus* and *E. smithii*, into a format that can be easily accessed by plantation managers and growers. The decision to embed a live version of CABALA was taken about mid-way through the project when it became apparent that the number of possible combinations of input variables desired by the steering committee members was far more than was possible to run prior to release. This change means that there is a delay in running scenarios that have not been previously run, with each scenario usually taking around 1 minute. This is done on the server so the run-time is also dependent on the current server workload.

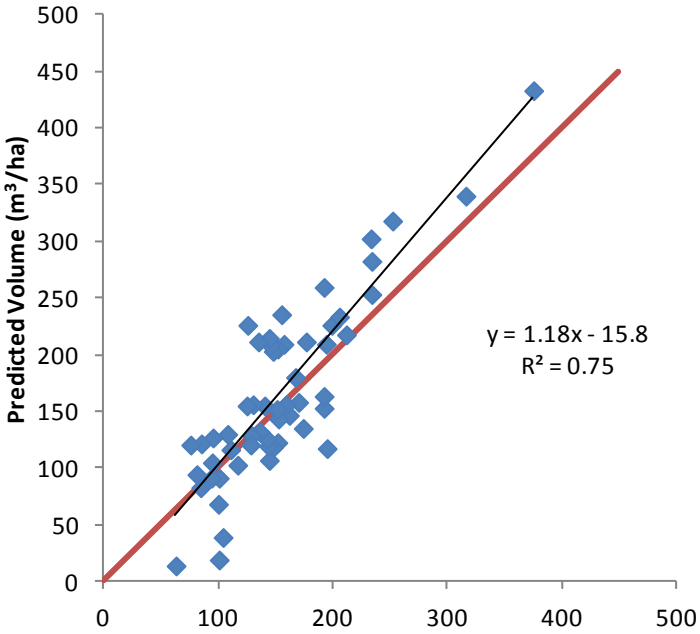
Results

CABALA model development and parameterisation for different species

For all plots used in developing the parameterisation sets for CABALA detailed growth, silvicultural and soils data were collected. For each species they covered the range of fertility, rainfall and temperature ranges within the estates as far as was feasible. The growth and silvicultural data were provided by industry partners and included planting dates and stems per ha at planting, detailed thinning information (sph and volumes removed), fertiliser events and any other potential impacts on growth such as nutrient deficiencies and insect attack Soil physical and nutrient data was either provided by the industry partner or drilling was undertaken as part of the project.

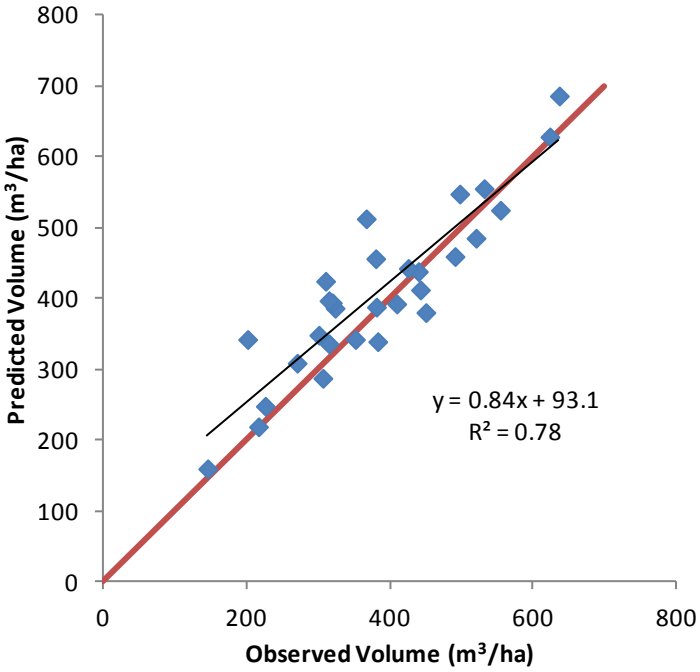
Daily rainfall and air temperature data for all plots were from the Bureau of Meteorology's Data Drill (http://www.longpaddock.qld.gov.au/silo/). The data in the Data Drill is synthetic; consisting of interpolated grids splined using data from meteorological station records but has the benefit of being available for all locations in Australia on a scale of 0.05 degree.

Fig 5 – CABALA validation using data from 58 *E. globulus* plots from Tasmania, Victoria, South Australia and Western Australia. Stands are at time of measurement were between 6 and 14 years of age and cover a range of silvicultural treatments including thinning and fertilisation.



Although some plots are poorly predicted there is no bias against the measures of fertility, rainfall or temperature indicating that predicative capacity is reasonable. Consistently poor predictions (under-estimates) are made on inland Victorian sites where frost limitations are over-predicted. Work being undertaken in a separate FWPA project is attempting to resolve the issue of fine downscaling to capture the effects of frosty and cold locations. Sites where mortality has been high are consistently over-predicted. The reasons for unexpected tree mortality are often not evident in the available data and consequently difficult to represent in model inputs.

Fig 6 – CABALA validation using data from 40 *P. radiata* plots from Tasmania, Victoria and South Australia. Stands are at time of measurement were between 12 and 40 years of age and cover a range of silvicultural treatments including thinning and fertilisation.

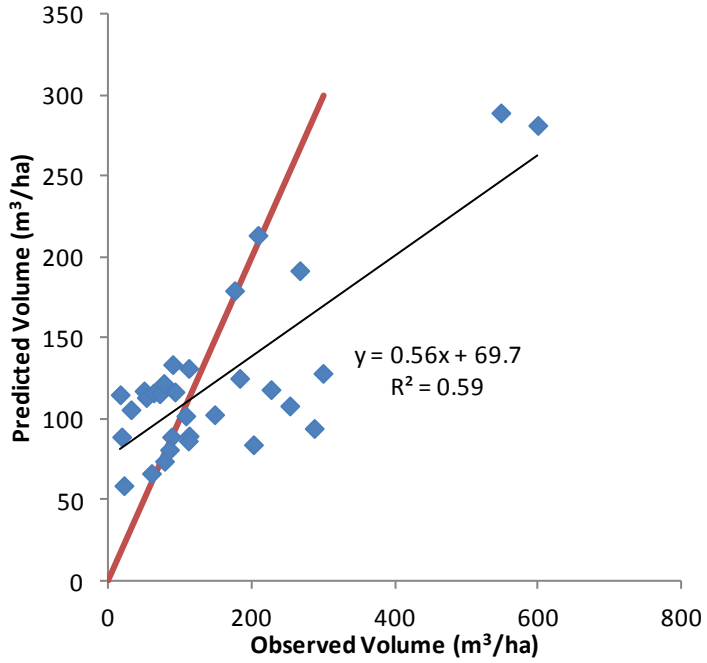


For *P. radiata* there are still some issues of over estimation of productivity in sites where temperatures are high and evaporation greatly exceeds precipitation. Work is being done to improve the predictions under these conditions. For the Tasmanian sites there are also some under predictions where terrain is complicated and the SILO weather is too coarse to capture site specific conditions.

Eucalyptus nitens

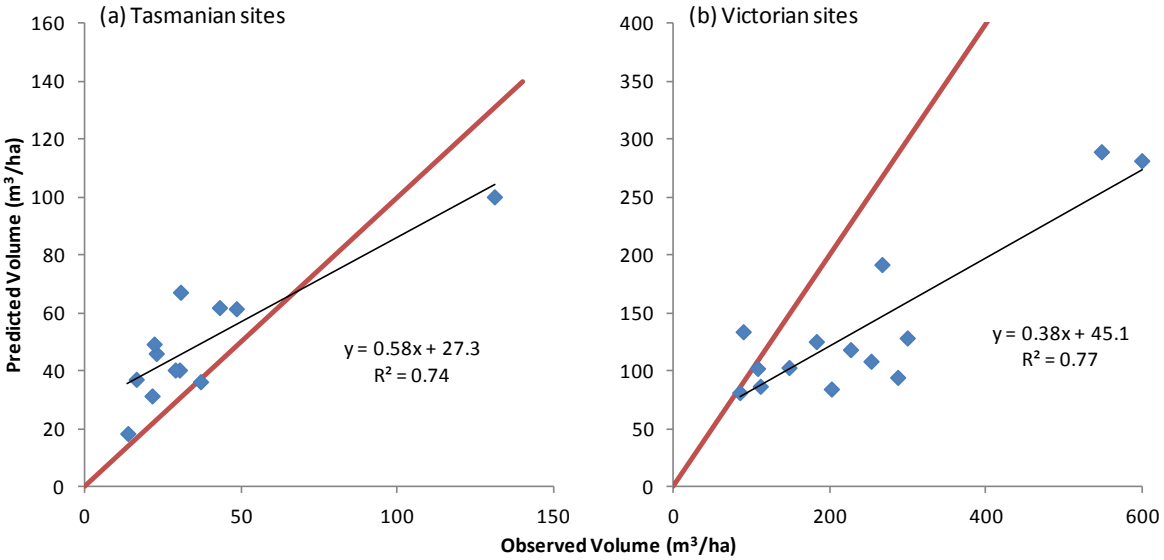
Parameterisation of *E. nitens* is still ongoing. There is a clear bias in the current parameter set, with low productivity sites being over predicted and high productivity sites generally under predicted (Fig. 7, Fig. 8). We are still working to understand why the observed growth is so low on some sites (sites are weed free). A number of these plots were 4-5 years old at measurement and further inventory may be useful as the stands more fully occupy the sites. Some of these sites have been planted on gravels and sand dunes, and the hydraulic and nitrogen mineralisation models in CABALA are unlikely to capture the processes accurately. Some of the sites are in areas of high terrain variability and predictions may be improved with fine downscaling of climate. Conversely, the sites in Victoria are generally under predicted and further work is required to understand why the reported growth rates are much higher.

Fig. 7 – CABALA validation using data from 32 *E. nitens* plots from Tasmania and Victoria. Stands are at time of measurement were between 3 and 12 years of age and are predominately un-thinned stands.



This parameter set needs to be used with caution until the underlying issues can be resolved as absolute measures of production may not be accurately predicted. A more suitable use may be to look at relative changes in production as a result of varying silviculture.

Fig. 8 – CABALA validation for *E. nitens*, split between Tasmania (a) and Victoria (b). Stand volume is generally over-predicted on Tasmanian sites and under-predicted on Victorian sites.

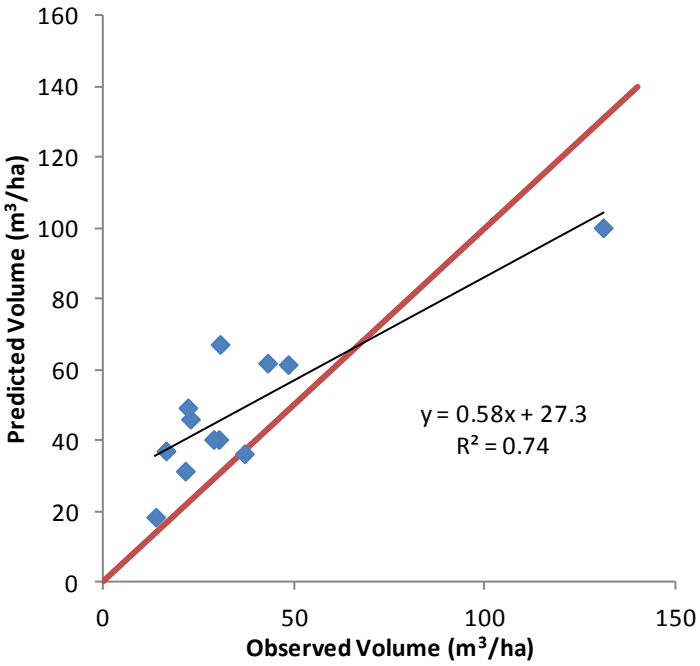


Eucalyptus smithii

Parameterisation of E. smithii is still ongoing. There are some limitations with the calibration dataset, all sites are young (3-5 years old), and all are relatively fertile. So we are uncertain as to how the model will perform on older stands and lower fertility sites. The model is generally over predicting (Fig. 9), the one site that is under predicted is the oldest site. At present there is little differentiation between the productivity of the shallow and deep sites in observed

volume and CABALA is only just starting to predict water stress as the soil profiles dry out. Additional data as the stands more fully occupy the site will help improve the parameter set. So care must be taken when using the model for predictions above age 5.

Fig. 9 – CABALA validation using data from 12 *E. smithii* plots from Western Australia. Stands are at time of measurement were between 3 and 5 years of age and are all on reasonably fertile sites.



Preliminary parameter sets are also available within FPOS for *P.pinaster*, and these will be refined into the future.

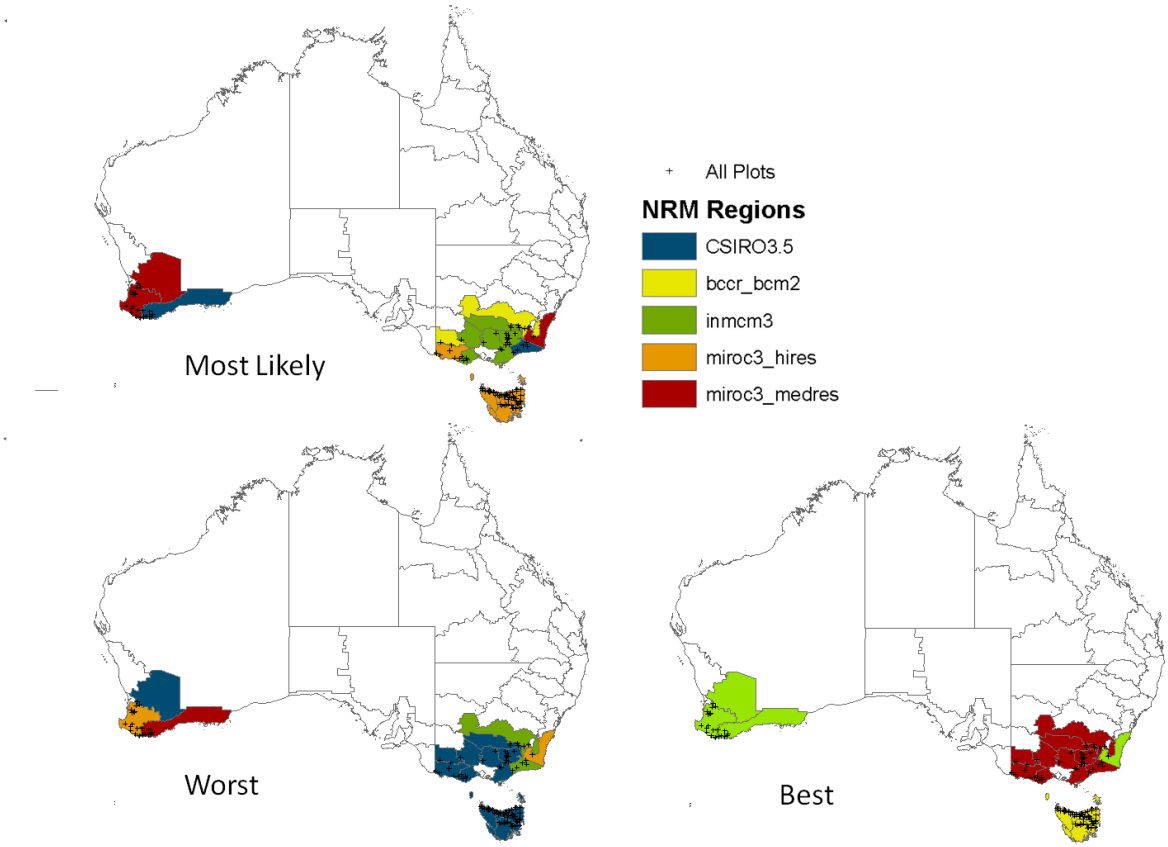
Climate model selection and application

At present, the Climate Futures Framework can only be used for regional assessments based on NRM boundaries. Each NRM region containing an FPOS climatic zone was run and the best, worst and most likely future climate was selected. Only a limited number of the 24 Global Circulation Models had maximum and minimum temperature change values available, resulting in a pool of only 5 models to select from (Fig. 10). The 5 models are shown in Table 2.

Table 2 – Summary of global circulation models (GCM's) used in the FPOS system.

Model	Publisher	Publication date
CSIRO 3.5	CSIRO	2006
bccr_bcm2	Bjerknes Centre for Climate Research, University of Bergen	2005
inmcm3	Institute of Numerical Mathematics, Russian Academy of Science, Russia	2004
miroc3_hires	Japanese Centre for Climate System Research	2004
miroc3_medres	Japanese Centre for Climate System Research	2004

Fig. 10 – The global circulation models selected in each NRM region. The colours represent the model selected for that region. Future climate predictions vary substantially across regions and what may be the most likely or best future climate in one region may be the worst in another. Note that 'best' is the model that predicts the highest rainfall and lowest temperature increase, 'worst' is the model that predicts the lowest rainfall and highest temperature increase, while 'most likely' is the temperature and rainfall changes that most of the models predict. Note that no NRM regions were assessed in South Australia, as the representative points for the climatic zones in the Green Triangle (which did extend into SA, see Fig. 2 in Appendix 2) were coincidentally located on the Victorian side of the border.



Downscaling future climates

Historical climate data for each climatic zone (refer to FPOS manual for more detail on climatic zones) was obtained from the Bureau of Meteorology's Data Drill (http://www.longpaddock.qld.gov.au/silo/). The data in the Data Drill is synthetic, consisting of interpolated grids splined using data from meteorological station records but has the benefit of being available for all locations in Australia with a resolution of 0.05 degrees. Blocks of 30 years of historical data were used for the base data, 1975-2005 as defined by the IPCC as the base historical climate.

A relatively simple stationary approach was used to modify the historical weather. The temperature and rainfall was modified using monthly averages from the potential future climates. Radiation was not adjusted as it is expected there will be only small changes of between -1 to + 2% (CSIRO, 2007). The monthly changes in temperature for the 2030 time period were added to the historical data. Rainfall was modified using proportional change (a simple additive approach is not appropriate given the variation in absolute rainfall across a single cell in the GCM grids).

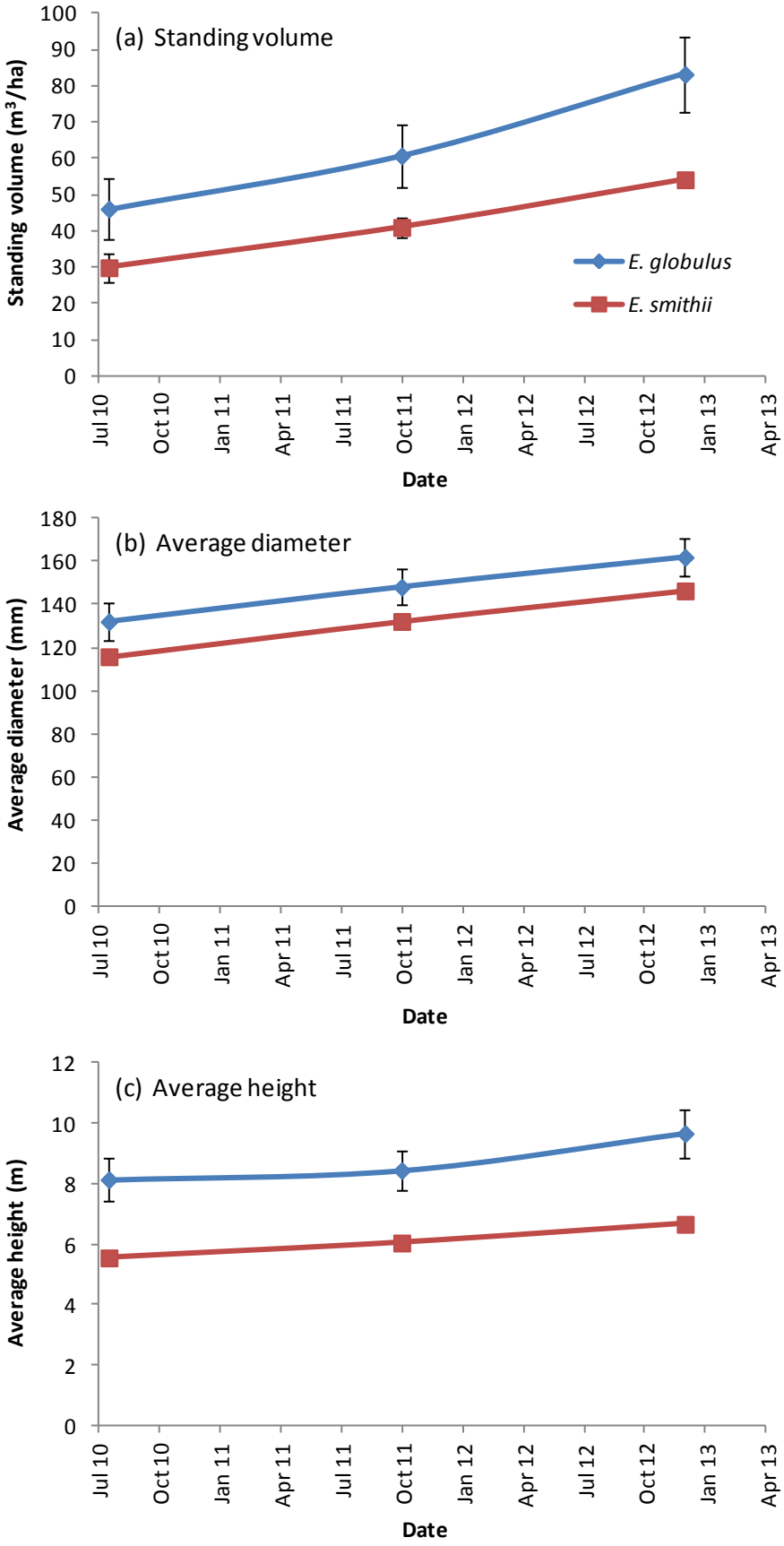
The average monthly climates were then calculated for each climatic zone over the entire 30 year sequence.

Detailed comparative studies into *E. smithii* and *E. globulus* in response to environment

Tree growth - overall

The standing volume in the *E. globulus* plots started higher than that of the *E. smithii* plots (46 m^3/ha versus 30 m^3/ha), and the productivity differential between the species widened, especially in the 3rd year of measurement (Fig. 11), mainly due to an increased height increment in 2012 (1.21 m in *E. globulus*, compared to 0.6 m in *E. smithii*).

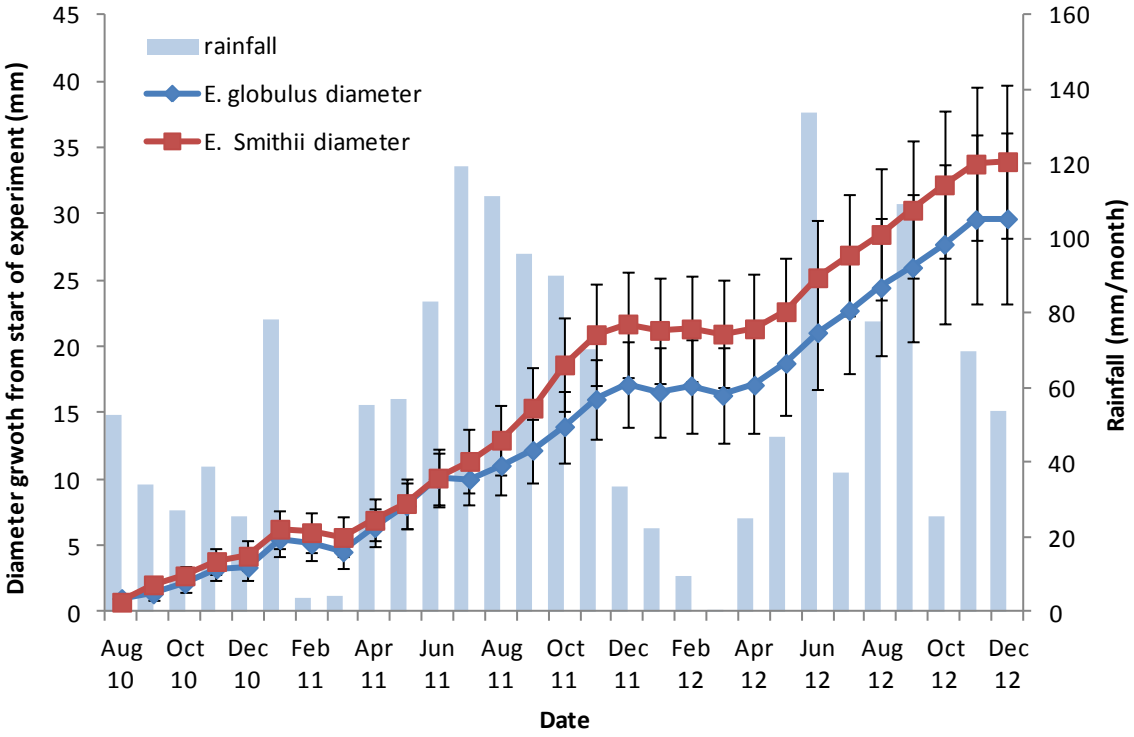
Fig. 11 – Measured standing volume (a), diameter (b) and height (c) of each species over the 2.5 year life of the experiment. Error bars show ± 1 SEM.



At a finer timescale, the dendrometers showed the pattern of diameter growth was highly responsive to rainfall (Fig. 12). Both species grew strongly from April through to December/January, and tended to plateau or even show a decrease in stem diameter over the summer months, typically when rainfall was below 20 mm/month. There was no apparent difference between the species in short-term diameter response to rainfall, although the *E. smithii* trees had a higher increment than the *E. globulus* trees that we measured. This difference in relative ranking was not reflected in the overall stand-level diameter increment (Fig. 11b), which was similar for both species (29.9 mm and 30.6 mm for *E. globulus* and *E. smithii*, respectively for the period July 2010-June 2012).

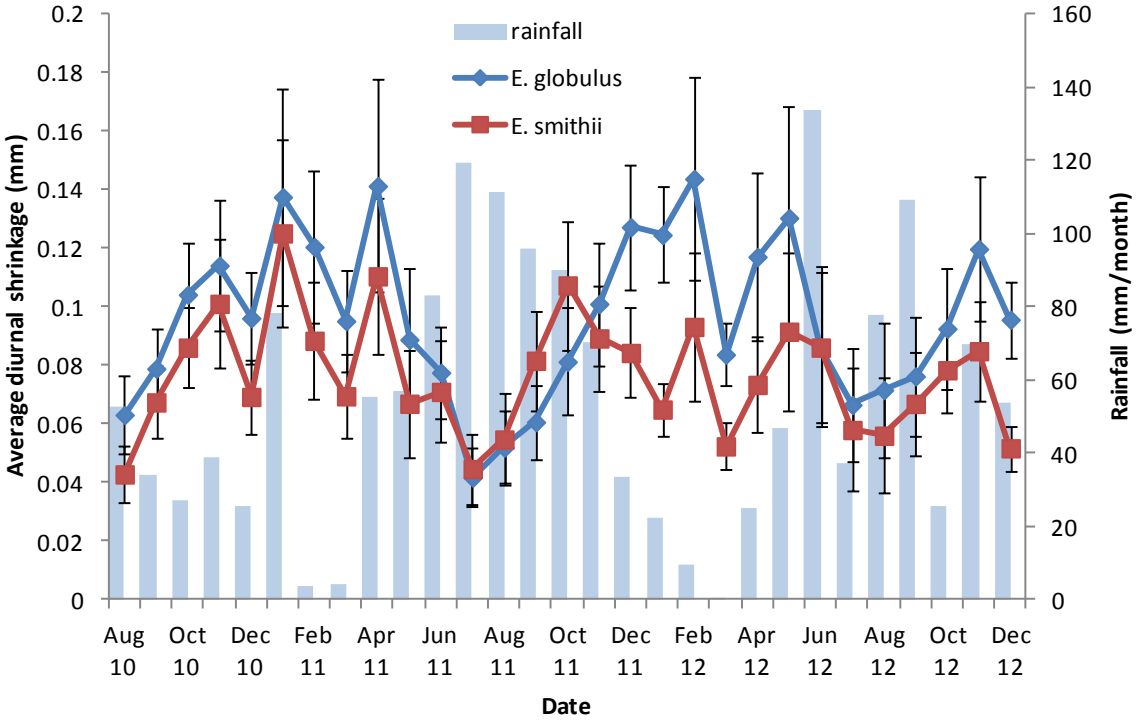
Tree growth – fine time scale

Fig. 12 – Monthly tree diameter and rainfall (derived from SILO). Note that rainfall bars represent the rainfall in the month prior to each of the diameter points. Error bars represent ± 1 standard error of the mean.



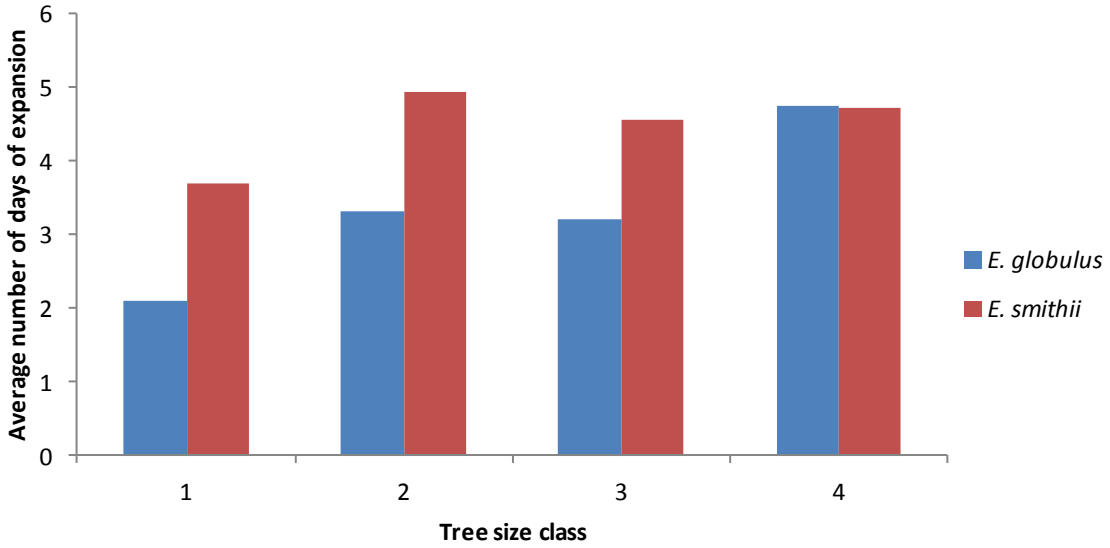
The stems of both species exhibited significant diurnal shrinkage (Fig. 13), which was least during winter (typically 0.05 mm), and greatest during summer (typically 0.1-0.15 mm). *E. globulus* tended to exhibit a greater shrinkage than *E. smithii*, especially during the extended dry summer of 2011/12.

Fig. 13 – Monthly diurnal shrinkage and coincident rainfall. Error bars show ± 1 SEM



Net stem diameter growth after rainfall was generally restricted to only a few days after a rainfall event for both species, averaging from 2 days (for the smallest size *E. globulus*) to around 5 days (for the largest size class trees, Fig. 14). However, the trees also exhibited the capacity for continuous stem growth for up to 140 days for one of the *E. smithii* trees, and up to 96 days for one of the *E. globulus* trees.

Fig. 14 – Average number of days of net stem expansion by size class (1 = lowest quartile, 4 = highest quartile of stem diameter). Note that there is large variation around these data points, so the error bars are not shown.



The number of days of continuous stem expansion was directly related to the rainfall occurring during the expansion period. Fig. 15 shows the overall relationship, whilst Fig. 16 shows the lower end of the data which has the more than ¾ of the data points (<15 days continuous expansion). There is no obvious difference between the species in this attribute.

Fig. 15 – Relationship between the number of days of continuous stem expansion and the rainfall during that time

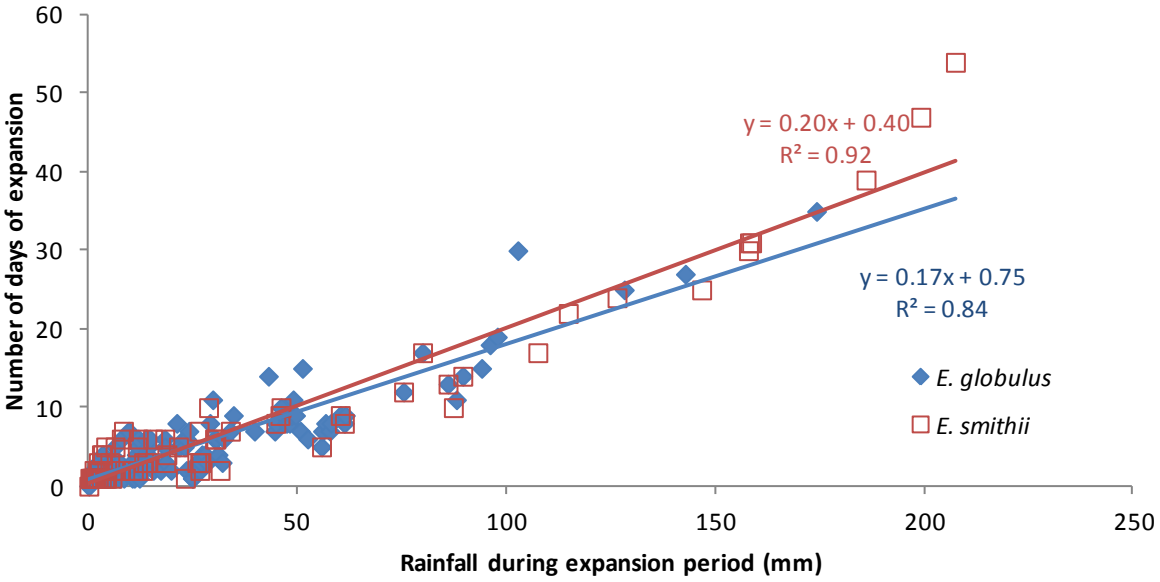
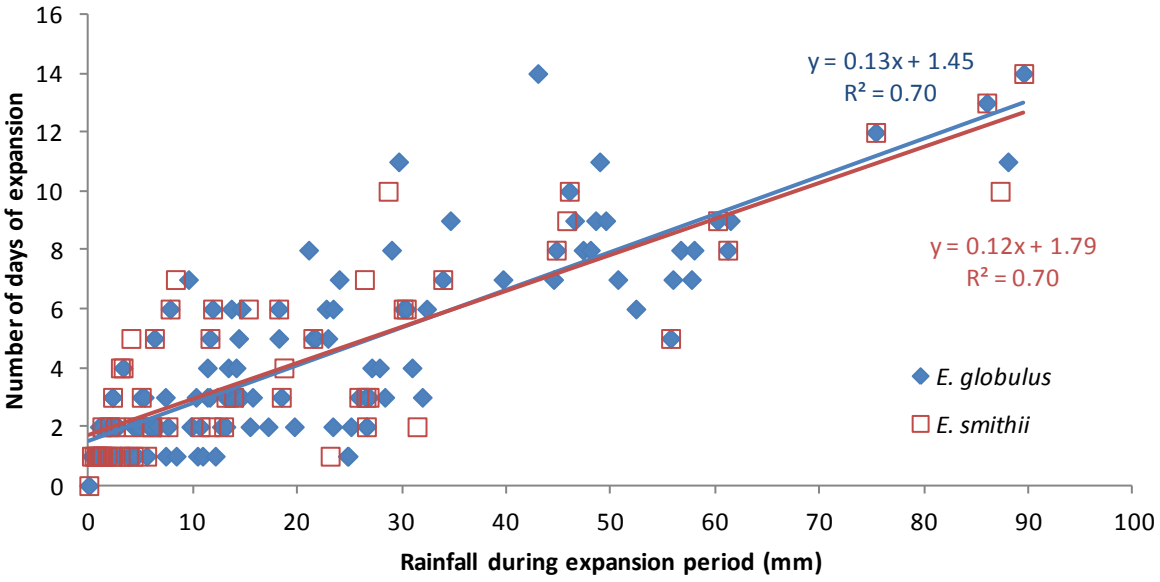


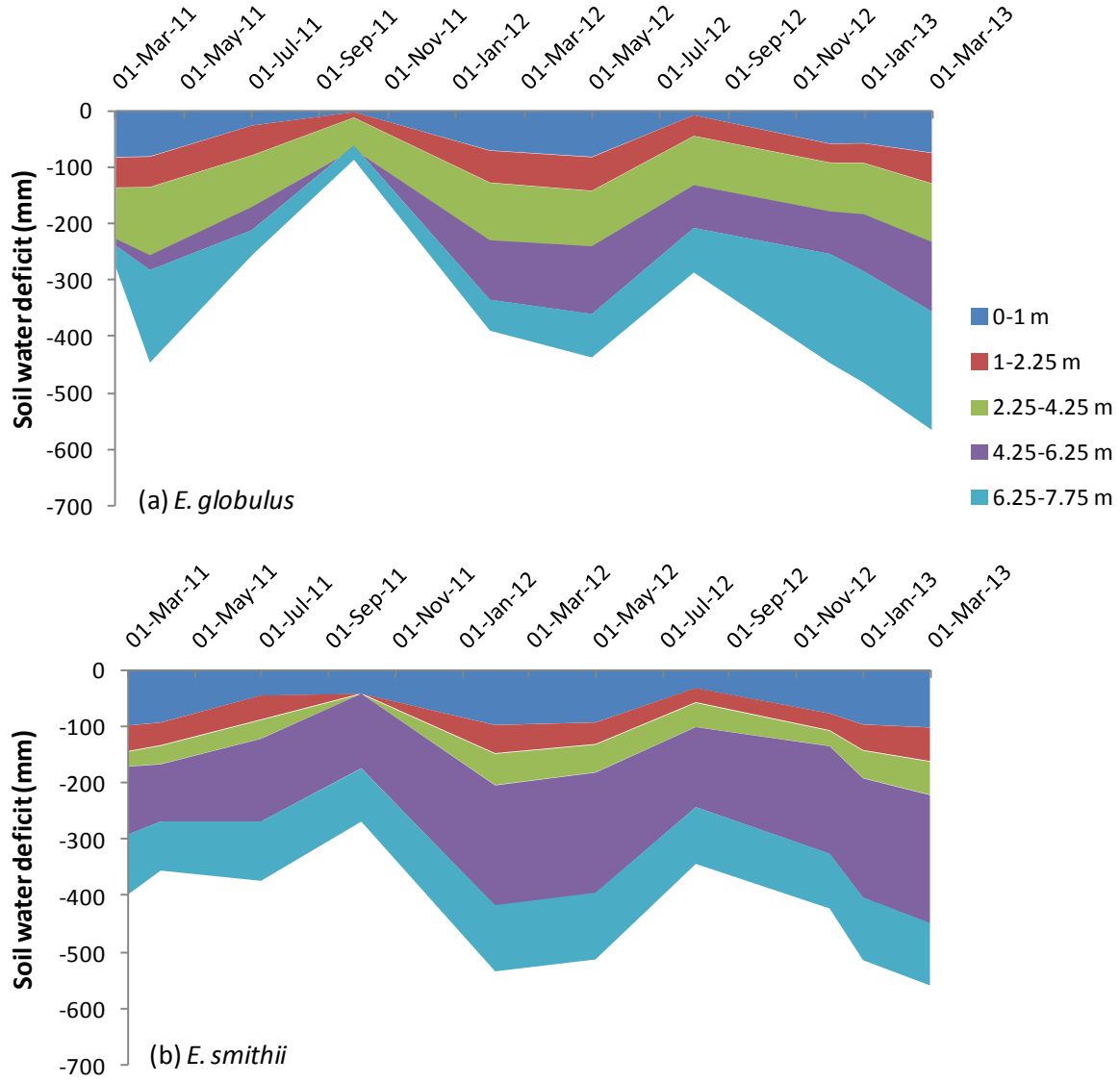
Fig. 16 – Relationship between the number of days of continuous stem expansion and the rainfall during that time, limited to periods with 15 or less days of continuous stem expansion (this is the bottom end of the data in Fig. 15).



Soil moisture

The soil moisture measurements (Fig. 17) suggested that both species drew heavily on the soil water available down to 2.25 metres. Interestingly, the winter of 2011 showed different recharge patterns between the species, with the middle layers (1-4.25m) recharging under *E. smithii*, and the lower layers (4.25-7.75 m) recharging more under *E. globulus*. *E. smithii* tended to maintain a larger soil water deficit in the lower layers.

Fig. 17 – Measured soil water deficit under *E. globulus* (a) and *E. smithii* (b) over the duration of the experiment



Gas exchange

The diurnal gas exchange rates were measured at 5 times during the experiment, under different seasonal conditions. Only 2 of these occasions had suitable weather to permit a full diurnal (daylight period) measurement, with rainfall interfering with the other measures such that gas exchange could only be assessed 2-3 times during the day. The highest photosynthetic rates were typically observed in the early or mid-morning (Fig. 18), and when these mid-morning rates were plotted over time (Fig. 19), it is evident that the peak photosynthetic times were in spring. Several of the measures had low or negative photosynthetic rates (November 2010 and April 2011), and these low photosynthetic rates were associated with high temperatures (>35°C) and high vapour pressure deficits (>4 KPa). The envelope of the relationship between VPD and conductance (Fig. 20) is important to describe a species response to environmental conditions within CABALA, and it suggested that the *E. globulus* trees had slightly more stomatal control at VPDs between about 2 and 4 KPa.

Fig. 18 – Diurnal photosynthesis (from 4 of 5 measurement occasions). Note that inclement weather prevented full acquisition of the latter 2 diurnal curves.

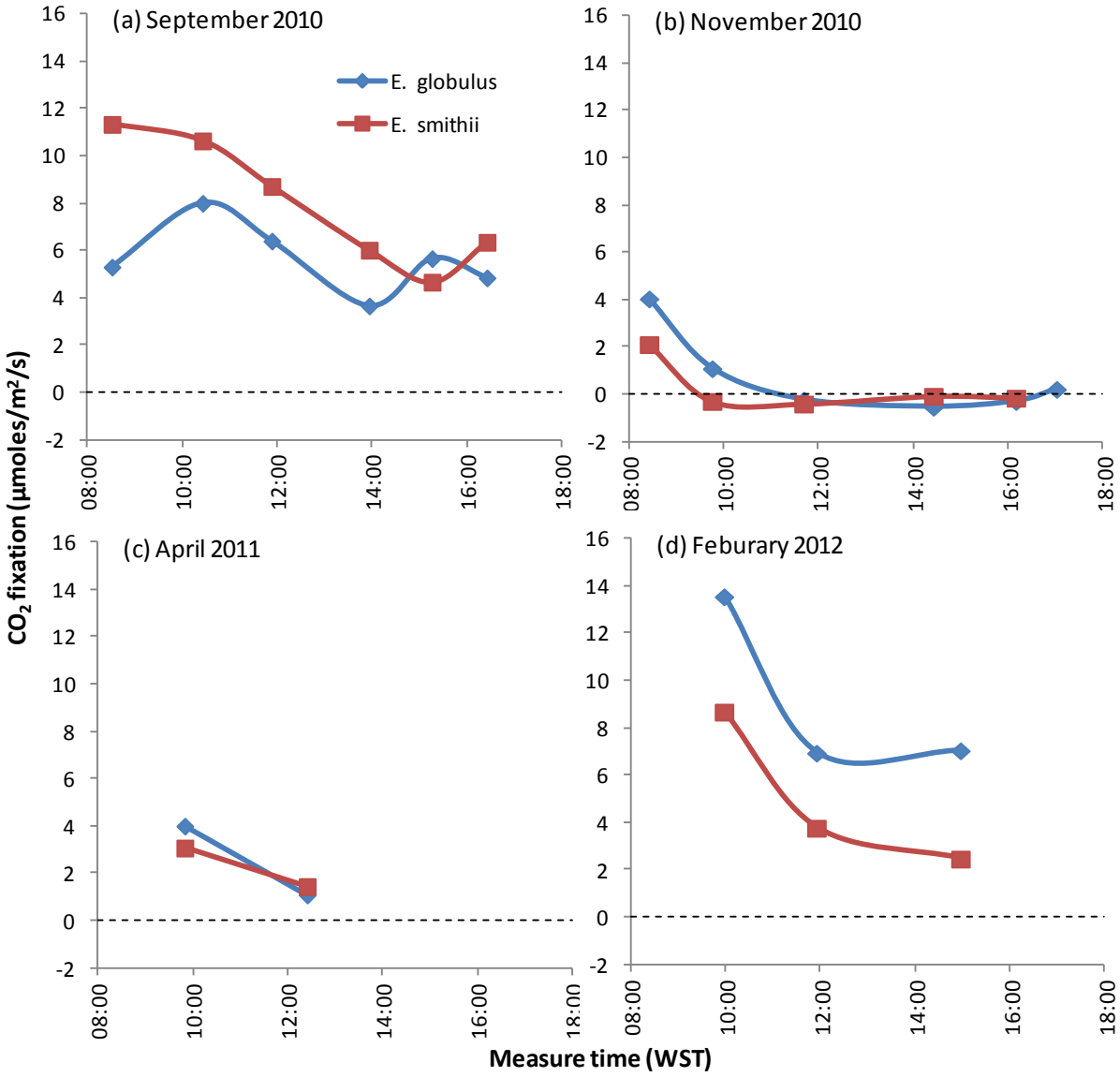


Fig. 19 – Measured photosynthetic rate at around 10 am at each of the measurement times. Error bars show ± 1 SEM. Note that only *E. smithii* was assessed in November 2011.

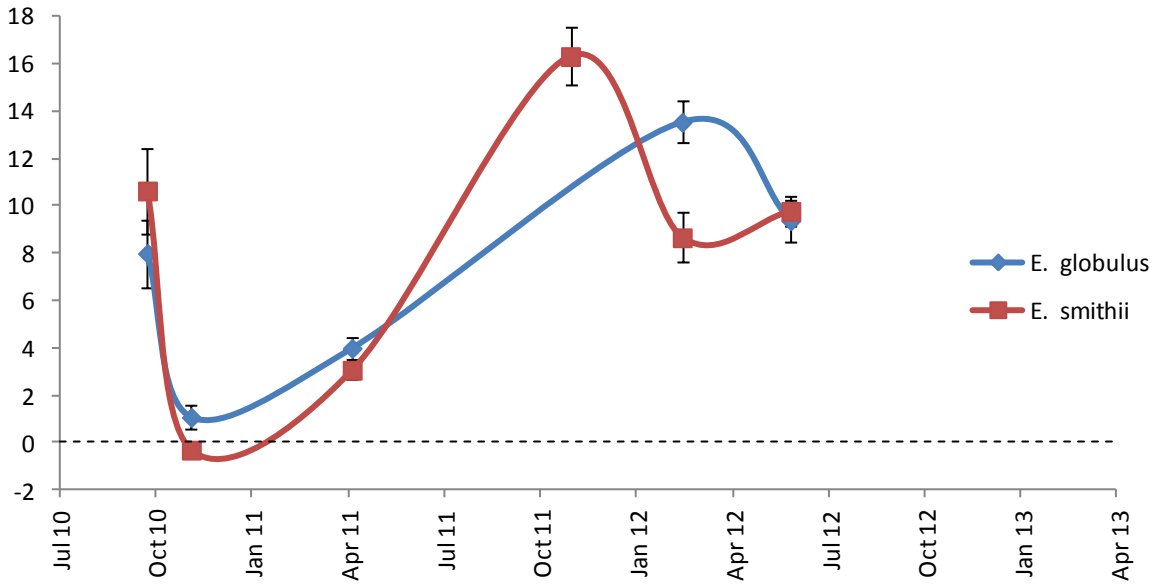
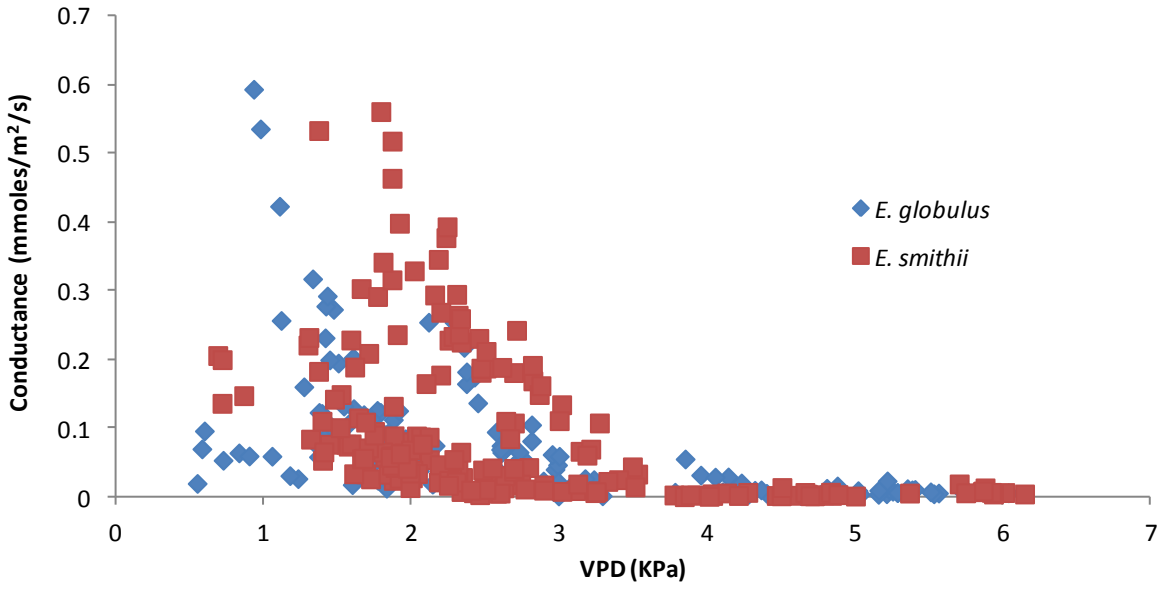


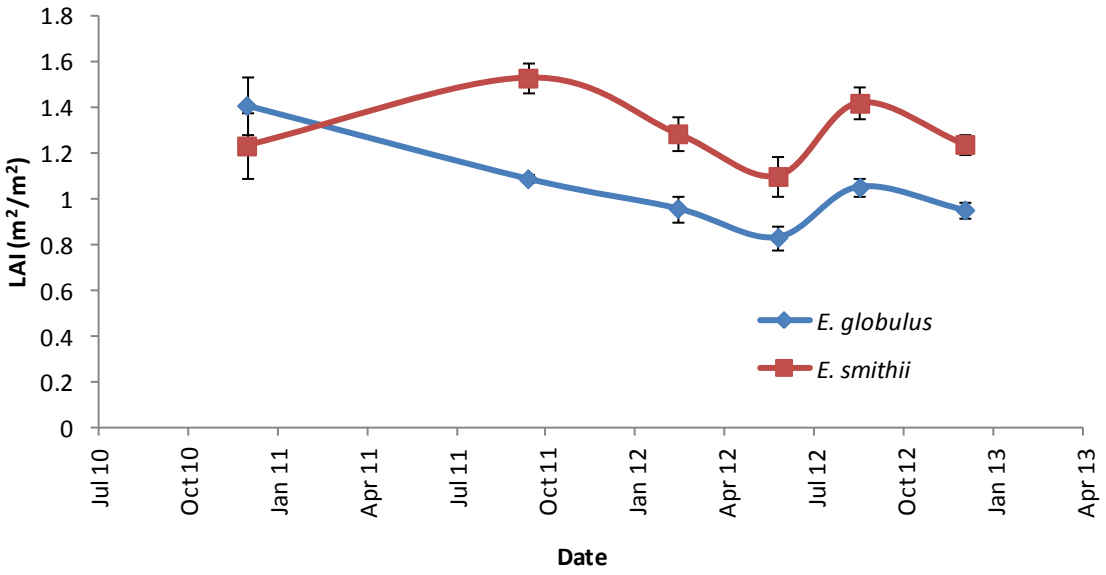
Fig. 20 –Relationship between measured leaf conductance and leaf vapour pressure deficit. The envelope of this relationship defines the phenomenological model used in CABALA to describe maximum possible conductance.



LAI

The leaf area index (LAI) showed similar trends between the 2 species (Fig. 21), with the exception that *E. smithii* LAI was tending to increase over the first year of measurement, while the *E. globulus* LAI had already peaked and showed a decline until the spring of 2012, when both species had marginal increases in LAI. *E. smithii* maintained a higher LAI than *E. globulus* (around 0.3 units) from October 2011 until the end of the experiment.

Fig. 21 – Leaf area index over the duration of the experiment. Error bars show ± 1 standard error of the mean.



Leaf water potential

Both species showed very similar patterns of pre-dawn water potential over the experimental period (Fig. 22), but *E. smithii* tended to have a lower pre-dawn water potential at almost all of the measurement times, suggesting that it was slightly more water stressed than *E. globulus* at any given time. It is worth while noting that the biggest difference in pre-dawn water potential (in February 2012) was also associated with the biggest difference in 10am photosynthetic rate (cf Fig. 19). The midday water potential also showed a similar trend in both species over time (Fig. 23), with *E. smithii* tending to have a similar or lower water potential to *E. globulus*.

Fig. 22 – Pre-dawn water potential over the duration of the experiment. Error bars show ± 1 SEM.

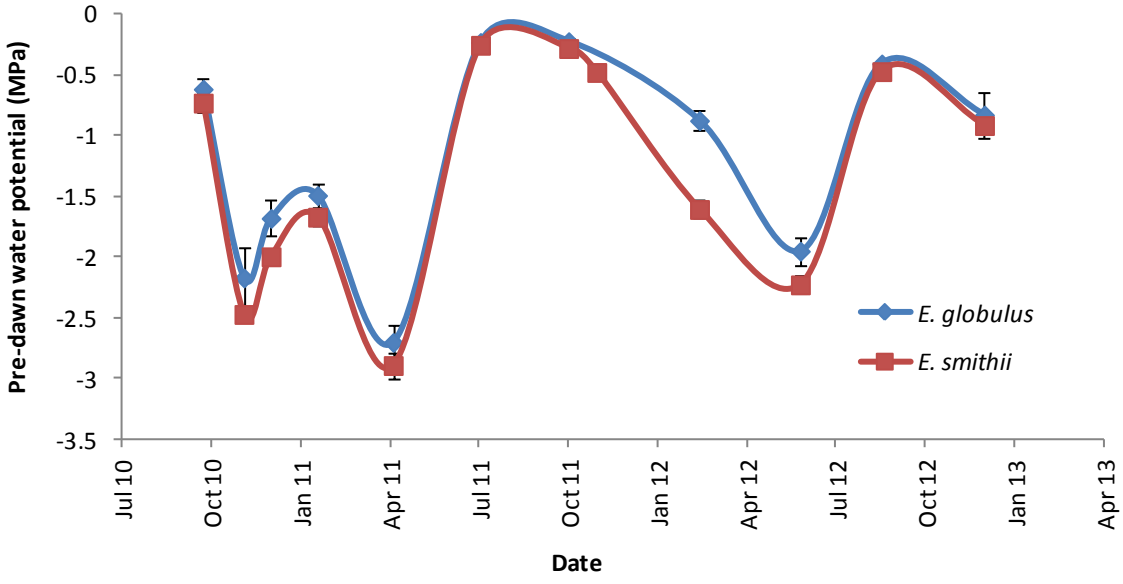
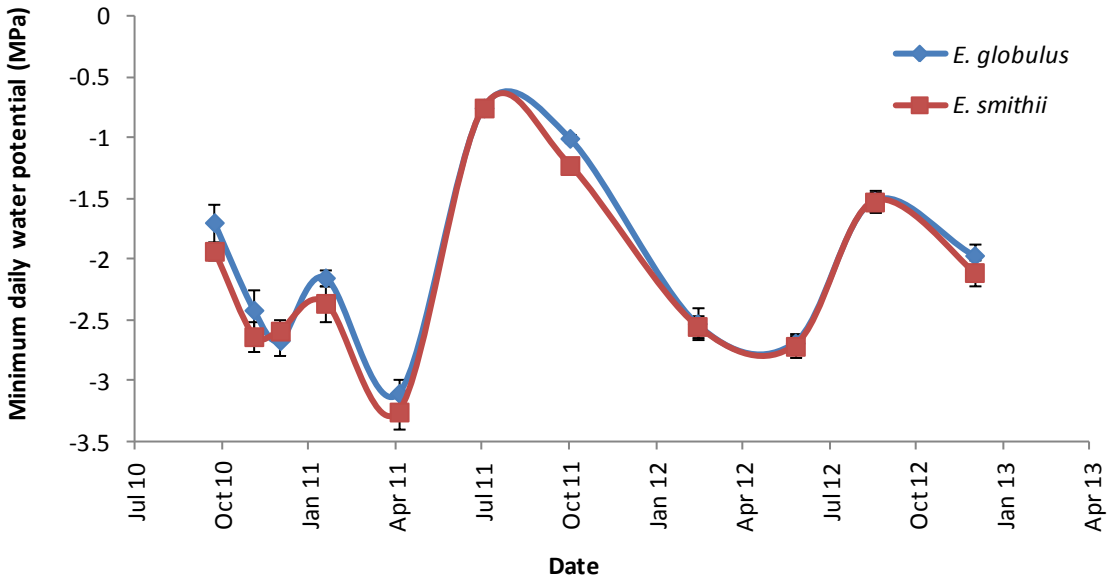


Fig. 23 – Minimum daily water potential measured over the duration of the experiment. Error bars show ± 1 SEM.



FPOS interface development

The FPOS interface was successfully developed and released. The user manual (see Appendix 2) describes the system, its assumptions and flow of logic, so this is not repeated here.

Discussion

CABALA model development and species parameterisation

Species-specific parameter sets for the CABALA model have been developed from the daily weather conditions prevailing during the growth of plantations. This has some implications for how well CABALA will predict growth using long term average climatic data. Overall with *P. radiata* and *E. globulus* there is no consistent bias in the predictions when using monthly data (however predictions are not as accurate). This may become prove to be a more serious issue for the *E. smithii* parameter set where all the validation plots were planted at about the same time, so the sites have had the same period of historical weather. For *P. radiata*, *E. globulus* and *E. nitens*, the plots span a much larger weather span, so there is less of a bias. A second parameter will need to be built for *E. Smithii* using long term average monthly data.

There are also some unknowns predicting growth into future climates under elevated CO_2. We presume that for the medium term (at least to 2030) the range of conditions of temperature and rainfall are likely to be encompassed within the historical data record. If plantation performance can be reliably simulated for historical situations across the environmental domain in which the species are planted we can be more confident of future predictions. The inclusion of the Farquhar model of photosynthesis appears to have improved CABALA's performance under elevated CO_2 with nutrient and water limited sites showing a much smaller response than non-limited sites as shown by Norby et al. (2010).

Climate model selection and application

There is much uncertainty around future climate projections. While there is agreement that greenhouse gases in the atmosphere will increase, we do not know how quickly or to what level emissions will increase and the extent to which global temperatures will respond to elevated greenhouse gases. There is also uncertainty about how GCM results will reflect regional or local climate. As the models become more sophisticated these uncertainties will be minimised but never eliminated. So, when trying to assess the impact of future climates on forest growth it is important to understand there will be range in potential futures, rather than a single future.

There are some limitations in using the Climate Futures Framework. The NRM boundaries do not always follow climatic gradients and as a result there will be occasions where the worst and most likely future climates are reversed. Often, the most likely is actually very close to the worst outcome and the results will be very similar. To allow a uniform approach across the NRM regions we have assumed the changes in average temperature and annual rainfall accurately define the best, worst and most likely outcome. This may not always be the case. We chose a relatively simple, stationary approach to the statistical downscaling of the future climates. This method is appropriate for use with average monthly climate but there are some limitations. Most importantly, there is the assumption there is no change in the number of rain days in future scenarios compared to historical climate. Where there is an overall drying trend, this can result in an increased number of days with very small rainfall events. It is more likely rainfall will be concentrated into fewer rain days with more intense precipitation events. Nor does it capture the predicted increase in extreme weather events, such as droughts.

Comparative physiology of *E. smithii* and *E. globulus*

The studies into the comparative physiology of *E. smithii* and *E. globulus* did not draw out any large differences in the capacity of *E. smithii* to respond to the drier or hotter conditions that are likely to prevail in some areas of the plantation estate under likely future climate change. This does not mean that *E. smithii* does not convey a benefit for these conditions, just that we were not able to specifically identify what the cause of that benefit may be. However, it is worth noting that *E. smithii* appears to be more of a steady performer than *E. globulus*, showing the following attributes:

- A substantially lower initial standing volume in our experiment (Fig. 8), and lower height growth response between the October 2011 and January 2013 measures. This latter growth period was not associated with significantly different depletion of the soil water stores under *E. globulus* compared to *E. smithii* (Fig. 14).
- Lesser diurnal shrinkage at most of the measurement times, but especially in the dry summer periods

It is also apparent that initial survival rates of *E. smithii* have been lower than for *E. globulus* in many of the plantations that we initially surveyed (although not at Shuttleworth where this experiment was conducted), with the lower stocking rate possibly conveying a natural advantage to *E. smithii* plantations in drought conditions. White et al. (2011) also used the Shuttleworth site to compare drought sensitivity between *E. globulus* and *E. smithii*, and they found that there were few differences between the 2 species in their hydraulic characteristics that relate to drought sensitivity. Mitchell et al. (2012) however, did show that pot-grown *E. smithii* had a slightly longer survival than *E. globulus* (92 days vs 69 days) under drought conditions, but the differences between these 2 species were small compared to *Pinus* species, which exhibited a much greater tolerance to drought conditions. Thus planting of *E. smithii* may convey some survival advantage under extreme drought conditions, but this is likely to have a cost of lower biomass production. It is likely that a similar level of drought tolerance could be attained in these plantations through management of stocking rates of *E. globulus* instead of changing species.

Conclusions

This project has developed a forestry plantation decision support system to allow users to explore the impacts of various management, climate and species choices on predicted productivity and profitability. The tool that has been produced is not designed to answer all questions or to be the definitive reference for all situations, but rather its intended use is to support managers in their decision making processes about understanding the relative impacts of site selection, management regime and future climate on the predicted productivity and profitability.

Recommendations

The FPOS tool allows managers and growers to understand the predicted impacts of climate change, rainfall variability, management (including stocking rate and thinning regime), and site (climate, soil type, soil depth, soil fertility) on plantation productivity and profitability. Adoption of the system to aid managers in site selection, and site management (including over multiple rotations) could easily improve productivity and/or reduce risk by at least 10% at many sites. The system provides a wealth of information currently, and is also a potential platform for delivery of new research output as it is generated. The CRC Forestry, FWPA and developers are keen to assist with deployment and welcome feedback or suggestions for improvement.

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Researcher’s Disclaimer

The following disclaimer applies to the use of the FPOS system, and use of the system implies acceptance of this disclaimer.

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Appendix 1 – FPOS Climatic Zones and future climate scenarios. The latitude and longitude is the location of a representative SILO cell within the climate zones identified.

FPOS Climate Zone	Latitude	Longitude	NRM Region	Worst Scenario	Most Likely Scenario	Best Scenario
CZ001	143.1	-36.8	North Central	CSIRO3.5	inmcm3	miroc3_medres
CZ002	141.4	-37	Wimmera	CSIRO3.5	bccr_bcm2	miroc3_medres
CZ003	144.95	-37.05	Goulburn Broken	CSIRO3.5	inmcm3	miroc3_medres
CZ004	142.15	-37.7	Glenelg Hopkins	CSIRO3.5	miroc3_hires	miroc3_medres
CZ005	143.5	-38.3	Corangamite	CSIRO3.5	inmcm3	miroc3_medres
CZ006	141.05	-37.9	Glenelg Hopkins	CSIRO3.5	miroc3_hires	miroc3_medres
CZ007	142.55	-38.3	Glenelg Hopkins	CSIRO3.5	miroc3_hires	miroc3_medres
CZ008	141.35	-38.05	Glenelg Hopkins	CSIRO3.5	miroc3_hires	miroc3_medres
CZ009	142.95	-38.35	Glenelg Hopkins	CSIRO3.5	miroc3_hires	miroc3_medres
CZ010	142.3	-37.25	Glenelg Hopkins	CSIRO3.5	miroc3_hires	miroc3_medres
CZ011	143.3	-38.5	Corangamite	CSIRO3.5	inmcm3	miroc3_medres
CZ012	143.6	-38.45	Corangamite	CSIRO3.5	inmcm3	miroc3_medres
CZ013	145.95	-36.25	Goulburn Broken	CSIRO3.5	inmcm3	miroc3_medres
CZ014	149	-36.55	Southern Rivers	miroc3_hires	miroc3_medres	inmcm3
CZ015	147.15	-35.65	Murray	CSIRO3.5	inmcm3	miroc3_medres
CZ016	148.5	-37	East Gippsland	inmcm3	CSIRO3.5	miroc3_medres
CZ017	147.4	-37.85	East Gippsland	inmcm3	CSIRO3.5	miroc3_medres
CZ018	147.2	-35.8	Murray	CSIRO3.5	inmcm3	miroc3_medres
CZ019	147.75	-37.6	East Gippsland	inmcm3	CSIRO3.5	miroc3_medres
CZ020	143.15	-38.2	Corangamite	CSIRO3.5	inmcm3	miroc3_medres
CZ021	147.8	-35.6	Murrumbidgee	inmcm3	bccr_bcm2	miroc3_medres
CZ022	148.2	-37.25	East Gippsland	inmcm3	CSIRO3.5	miroc3_medres
CZ023	146.8	-36.3	North East	CSIRO3.5	inmcm3	miroc3_medres
CZ024	148.55	-37.35	East Gippsland	inmcm3	CSIRO3.5	miroc3_medres
CZ025	147.85	-35.8	Murray	CSIRO3.5	inmcm3	miroc3_medres
CZ026	148.7	-35.75	Southern Rivers	miroc3_hires	miroc3_medres	inmcm3
CZ027	146.85	-36.6	North East	CSIRO3.5	inmcm3	miroc3_medres
CZ028	148.3	-35.85	Murrumbidgee	inmcm3	bccr_bcm2	miroc3_medres
CZ029	146.95	-36.4	North East	CSIRO3.5	inmcm3	miroc3_medres
CZ030	147.55	-36.3	North East	CSIRO3.5	inmcm3	miroc3_medres
CZ031	146.45	-37.6	West Gippsland	CSIRO3.5	inmcm3	miroc3_medres
CZ032	146.85	-36.75	North East	CSIRO3.5	inmcm3	miroc3_medres
CZ033	146.9	-37	North East	CSIRO3.5	inmcm3	miroc3_medres
CZ034	146.3	-37.55	Goulburn Broken	CSIRO3.5	inmcm3	miroc3_medres
CZ035	146.95	-36.65	North East	CSIRO3.5	inmcm3	miroc3_medres
CZ036	147.05	-37.15	North East	CSIRO3.5	inmcm3	miroc3_medres
CZ037	147.05	-36.65	North East	CSIRO3.5	inmcm3	miroc3_medres
CZ038	146.75	-37.25	West Gippsland	CSIRO3.5	inmcm3	miroc3_medres
CZ039	116.7	-32.45	Avon	CSIRO3.5	miroc3_medres	inmcm3
CZ040	117.45	-34.45	South Coast	miroc3_medres	CSIRO3.5	inmcm3
CZ041	116.5	-32.2	Avon	CSIRO3.5	miroc3_medres	inmcm3
CZ042	116.9	-34.4	South Coast	miroc3_medres	CSIRO3.5	inmcm3
CZ043	117.7	-34.7	South Coast	miroc3_medres	CSIRO3.5	inmcm3
CZ044	116.4	-32.5	South West	miroc3_hires	miroc3_medres	inmcm3
CZ045	116.5	-34.4	South West	miroc3_hires	miroc3_medres	inmcm3
CZ046	117.65	-34.85	South Coast	miroc3_medres	CSIRO3.5	inmcm3
CZ047	116.3	-33	South West	miroc3_hires	miroc3_medres	inmcm3

FPOS Climate Zone	Latitude	Longitude	NRM Region	Worst Scenario	Most Likely Scenario	Best Scenario
CZ048	116.1	-34.05	South West	miroc3_hires	miroc3_medres	inmcm3
CZ049	117.45	-34.9	South Coast	miroc3_medres	CSIRO3.5	inmcm3
CZ050	116.2	-33.05	South West	miroc3_hires	miroc3_medres	inmcm3
CZ051	115.5	-34	South West	miroc3_hires	miroc3_medres	inmcm3
CZ052	117.15	-34.85	South Coast	miroc3_medres	CSIRO3.5	inmcm3
CZ053	116.05	-33.1	South West	miroc3_hires	miroc3_medres	inmcm3
CZ054	115.95	-34.2	South West	miroc3_hires	miroc3_medres	inmcm3
CZ055	116.95	-34.9	South Coast	miroc3_medres	CSIRO3.5	inmcm3
CZ056	116	-32.85	South West	miroc3_hires	miroc3_medres	inmcm3
CZ057	115.95	-34.55	South West	miroc3_hires	miroc3_medres	inmcm3
CZ058	116.35	-34.85	South West	miroc3_hires	miroc3_medres	inmcm3
CZ059	116.65	-35	South West	miroc3_hires	miroc3_medres	inmcm3
CZ060	147.95	-42.4	South	CSIRO3.5	miroc3_hires	bccr_bcm2
CZ061	147.65	-40.9	North	CSIRO3.5	miroc3_hires	bccr_bcm2
CZ062	148	-40.9	North	CSIRO3.5	miroc3_hires	bccr_bcm2
CZ063	147.3	-41.1	North	CSIRO3.5	miroc3_hires	bccr_bcm2
CZ064	146.4	-41.3	North West	CSIRO3.5	miroc3_hires	bccr_bcm2
CZ065	144.8	-40.8	North West	CSIRO3.5	miroc3_hires	bccr_bcm2
CZ066	144.9	-40.85	North West	CSIRO3.5	miroc3_hires	bccr_bcm2
CZ067	144.85	-40.95	North West	CSIRO3.5	miroc3_hires	bccr_bcm2
CZ068	147.25	-41.6	North	CSIRO3.5	miroc3_hires	bccr_bcm2
CZ069	147.05	-41.55	North	CSIRO3.5	miroc3_hires	bccr_bcm2
CZ070	147.65	-41.05	North	CSIRO3.5	miroc3_hires	bccr_bcm2
CZ071	147.1	-41.2	North	CSIRO3.5	miroc3_hires	bccr_bcm2
CZ072	146.85	-41.3	North	CSIRO3.5	miroc3_hires	bccr_bcm2
CZ073	145.1	-41.05	North West	CSIRO3.5	miroc3_hires	bccr_bcm2
CZ074	147.35	-41.75	North	CSIRO3.5	miroc3_hires	bccr_bcm2
CZ075	147.4	-41.6	North	CSIRO3.5	miroc3_hires	bccr_bcm2
CZ076	146.95	-41.7	North	CSIRO3.5	miroc3_hires	bccr_bcm2
CZ077	146.9	-41.4	North	CSIRO3.5	miroc3_hires	bccr_bcm2
CZ078	146.65	-41.5	North	CSIRO3.5	miroc3_hires	bccr_bcm2
CZ079	146.35	-41.4	North West	CSIRO3.5	miroc3_hires	bccr_bcm2
CZ080	146.2	-41.35	North West	CSIRO3.5	miroc3_hires	bccr_bcm2
CZ081	145.75	-41.1	North West	CSIRO3.5	miroc3_hires	bccr_bcm2
CZ082	145.4	-40.95	North West	CSIRO3.5	miroc3_hires	bccr_bcm2
CZ083	145.35	-41.05	North West	CSIRO3.5	miroc3_hires	bccr_bcm2
CZ084	145.4	-41.1	North West	CSIRO3.5	miroc3_hires	bccr_bcm2
CZ085	147.6	-42.4	South	CSIRO3.5	miroc3_hires	bccr_bcm2
CZ086	147.6	-42.5	South	CSIRO3.5	miroc3_hires	bccr_bcm2
CZ087	148	-41.85	North	CSIRO3.5	miroc3_hires	bccr_bcm2
CZ088	146.7	-41.55	North	CSIRO3.5	miroc3_hires	bccr_bcm2
CZ089	146.65	-41.4	North	CSIRO3.5	miroc3_hires	bccr_bcm2
CZ090	146.75	-41.3	North	CSIRO3.5	miroc3_hires	bccr_bcm2
CZ091	146.05	-41.2	North West	CSIRO3.5	miroc3_hires	bccr_bcm2
CZ092	146.1	-41.35	North West	CSIRO3.5	miroc3_hires	bccr_bcm2
CZ093	145.75	-41.15	North West	CSIRO3.5	miroc3_hires	bccr_bcm2
CZ094	145.45	-41.05	North West	CSIRO3.5	miroc3_hires	bccr_bcm2
CZ095	147.3	-42.45	South	CSIRO3.5	miroc3_hires	bccr_bcm2
CZ096	147.8	-42.1	North	CSIRO3.5	miroc3_hires	bccr_bcm2
CZ097	147.95	-41.9	South	CSIRO3.5	miroc3_hires	bccr_bcm2
CZ098	147.35	-41.5	North	CSIRO3.5	miroc3_hires	bccr_bcm2
CZ099	148	-41.4	North	CSIRO3.5	miroc3_hires	bccr_bcm2

FPOS Climate Zone	Latitude	Longitude	NRM Region	Worst Scenario	Most Likely Scenario	Best Scenario
CZ100	146.25	-41.5	North	CSIRO3.5	miroc3_hires	bccr_bcm2
CZ101	147.4	-42.4	South	CSIRO3.5	miroc3_hires	bccr_bcm2
CZ102	147.65	-41.95	North	CSIRO3.5	miroc3_hires	bccr_bcm2
CZ103	147.45	-41.55	North	CSIRO3.5	miroc3_hires	bccr_bcm2
CZ104	147.4	-41.5	North	CSIRO3.5	miroc3_hires	bccr_bcm2
CZ105	147.6	-41.65	North	CSIRO3.5	miroc3_hires	bccr_bcm2
CZ106	145.9	-41.35	North West	CSIRO3.5	miroc3_hires	bccr_bcm2
CZ107	147.25	-42.2	South	CSIRO3.5	miroc3_hires	bccr_bcm2
CZ108	146.85	-42.15	South	CSIRO3.5	miroc3_hires	bccr_bcm2
CZ109	147.75	-42.05	North	CSIRO3.5	miroc3_hires	bccr_bcm2
CZ110	146.7	-42.2	South	CSIRO3.5	miroc3_hires	bccr_bcm2
CZ111	146.45	-42.25	South	CSIRO3.5	miroc3_hires	bccr_bcm2
CZ112	146.95	-42.1	South	CSIRO3.5	miroc3_hires	bccr_bcm2
CZ113	146.7	-42.1	South	CSIRO3.5	miroc3_hires	bccr_bcm2
CZ114	147.4	-41.45	North	CSIRO3.5	miroc3_hires	bccr_bcm2
CZ115	146.3	-42.15	South	CSIRO3.5	miroc3_hires	bccr_bcm2

Appendix 2 – FPOS users manual

Introduction

The FPOS system is designed to deliver research outputs in a user-friendly format that is accessible to managers and growers of plantations in southern Australia. It allows the user to easily perform 'what if?' scenarios around management, site or climate/climate change.

FPOS Structure

FPOS is a web-based system that consists of the following elements

1. A live version of tree-size-distribution CABALA, configured to run with a large but limited number of combinations of inputs (See Table 1).
2. A database of pre-run CABALA outputs. Initially this database is small, but will grow as users request different combinations of scenarios. CABALA is run as new scenarios (ie. that aren't already in the database) are requested by the user. Once these have been run once they do not need to be run again unless the model is updated. The model is run on the server, and usually takes around 1 minute, depending on the server load.
3. Empirical processing modules to add value to CABALA outputs, including calculation of economic outputs, calculations of nutrient export rates under different harvesting regimes, and calculations of water use efficiency.
4. An interface to allow the user to easily extract information from the database and overlay model output with empirically processed information. The user can also print and/or save output from the interface for reporting.

Table 1 – Potential combinations of inputs to run CABALA

Input	Number of combinations	Notes
Climatic zone	115	
Species	5	Not all species will grow in all climatic zones
Stocking rates	15	
Soil fertility ratings	5	
Soil depths	5	Depths vary with region
Thinning regimes	30	Dependent on product type and species
Climate model	4	
Rainfall variation	5	
Total combinations*	129,375,000	

*Note that this is the maximum number of possible combinations, but some combinations cannot be selected in the interface because they are not sensible.

Climatic zones

The FPOS system is based around climatic zones. There are a total of 115 climatic zones. The zones in Western Australia (Fig. 1), the Green Triangle (Fig. 2) and Eastern Victoria (Fig. 3) are based on historical rainfall and evaporation, with each zone representing a 100 mm rainfall band and a 200 mm evaporation band while the zones in Tasmania (Fig. 4) are based on variation in historical rainfall and altitude.

Fig. 1 – FPOS Climatic zones in south-western Australia.

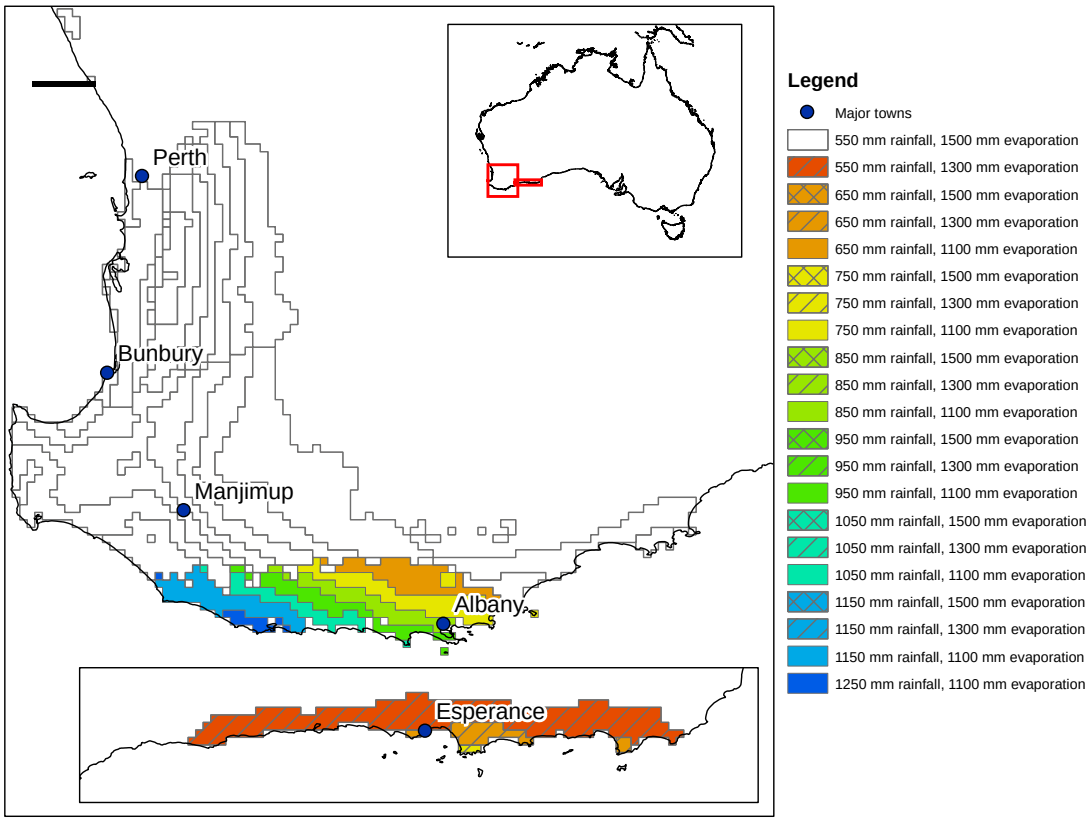

Perth
Bunbury
Manjimup
Albany
Esperance
Legend
Major towns
550 mm rainfall, 1500 mm evaporation
550 mm rainfall, 1300 mm evaporation
650 mm rainfall, 1500 mm evaporation
650 mm rainfall, 1300 mm evaporation
650 mm rainfall, 1100 mm evaporation
750 mm rainfall, 1500 mm evaporation
750 mm rainfall, 1300 mm evaporation
750 mm rainfall, 1100 mm evaporation
850 mm rainfall, 1500 mm evaporation
850 mm rainfall, 1300 mm evaporation
850 mm rainfall, 1100 mm evaporation
950 mm rainfall, 1500 mm evaporation
950 mm rainfall, 1300 mm evaporation
950 mm rainfall, 1100 mm evaporation
1050 mm rainfall, 1500 mm evaporation
1050 mm rainfall, 1300 mm evaporation
1050 mm rainfall, 1100 mm evaporation
1150 mm rainfall, 1500 mm evaporation
1150 mm rainfall, 1300 mm evaporation
1150 mm rainfall, 1100 mm evaporation
1250 mm rainfall, 1100 mm evaporation

Fig. 2 – FPOS Climatic zones in the Green Triangle region.

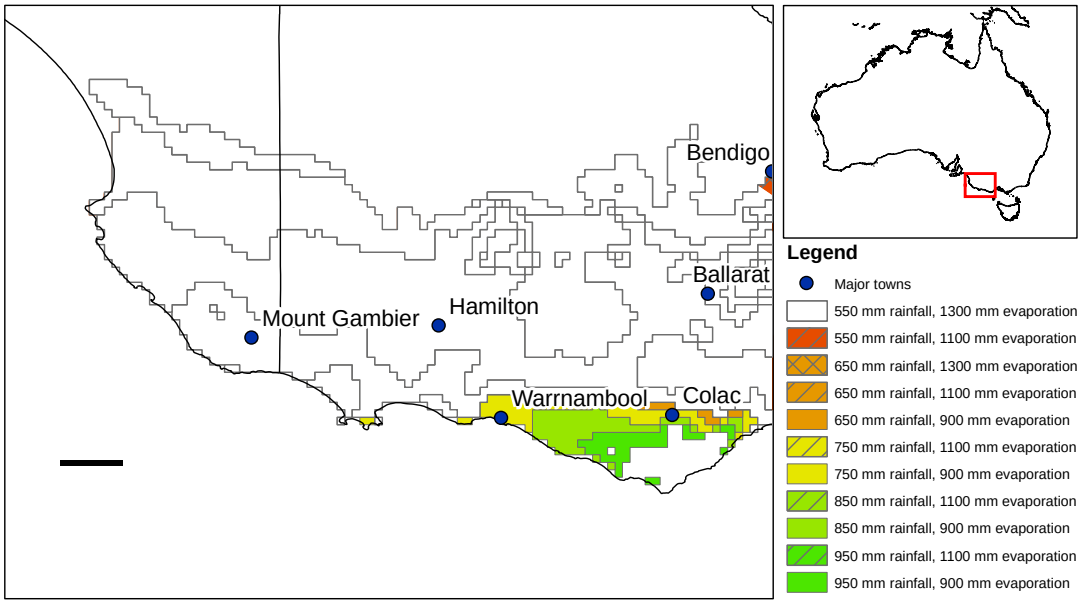

Bendigo
Ballarat
Mount Gambier
Hamilton
Warrnambool
Colac
Legend
Major towns
550 mm rainfall, 1300 mm evaporation
550 mm rainfall, 1100 mm evaporation
650 mm rainfall, 1300 mm evaporation
650 mm rainfall, 1100 mm evaporation
650 mm rainfall, 900 mm evaporation
750 mm rainfall, 1100 mm evaporation
750 mm rainfall, 900 mm evaporation
850 mm rainfall, 1100 mm evaporation
850 mm rainfall, 900 mm evaporation
950 mm rainfall, 1100 mm evaporation
950 mm rainfall, 900 mm evaporation

Fig. 3 – FPOS climatic zones in Victoria other than Green Triangle

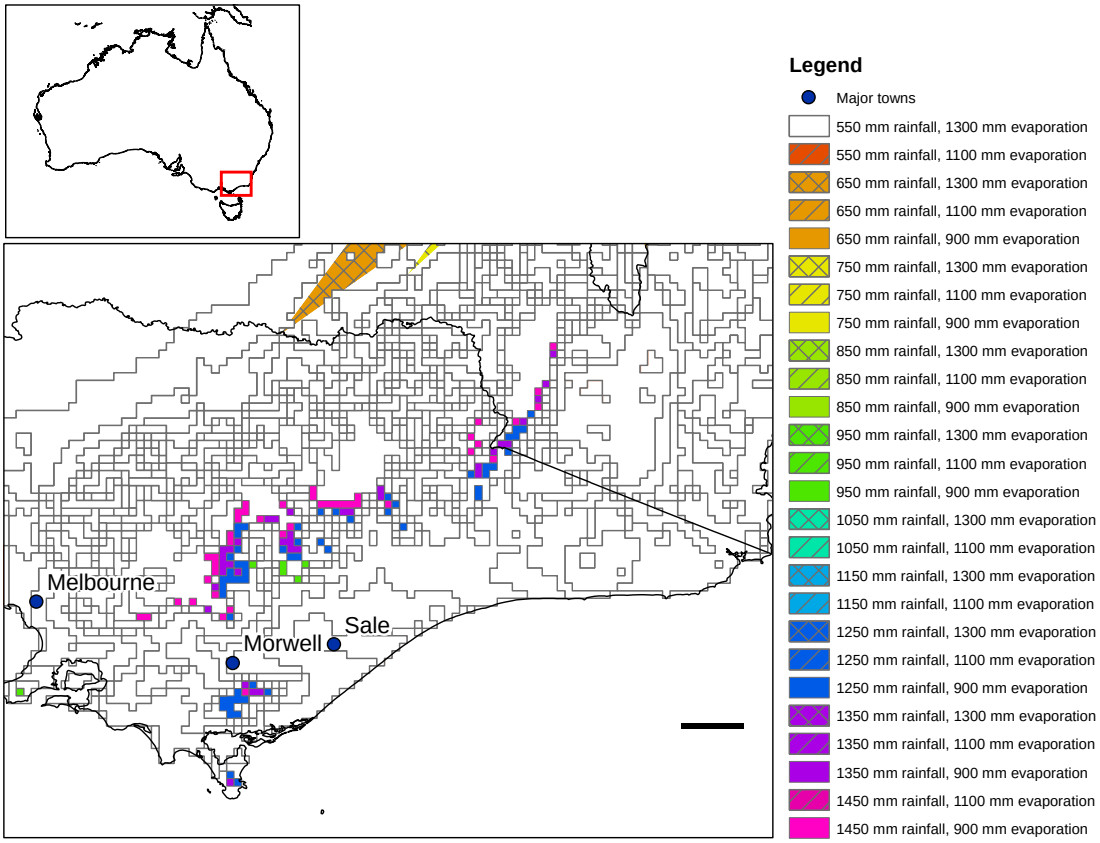
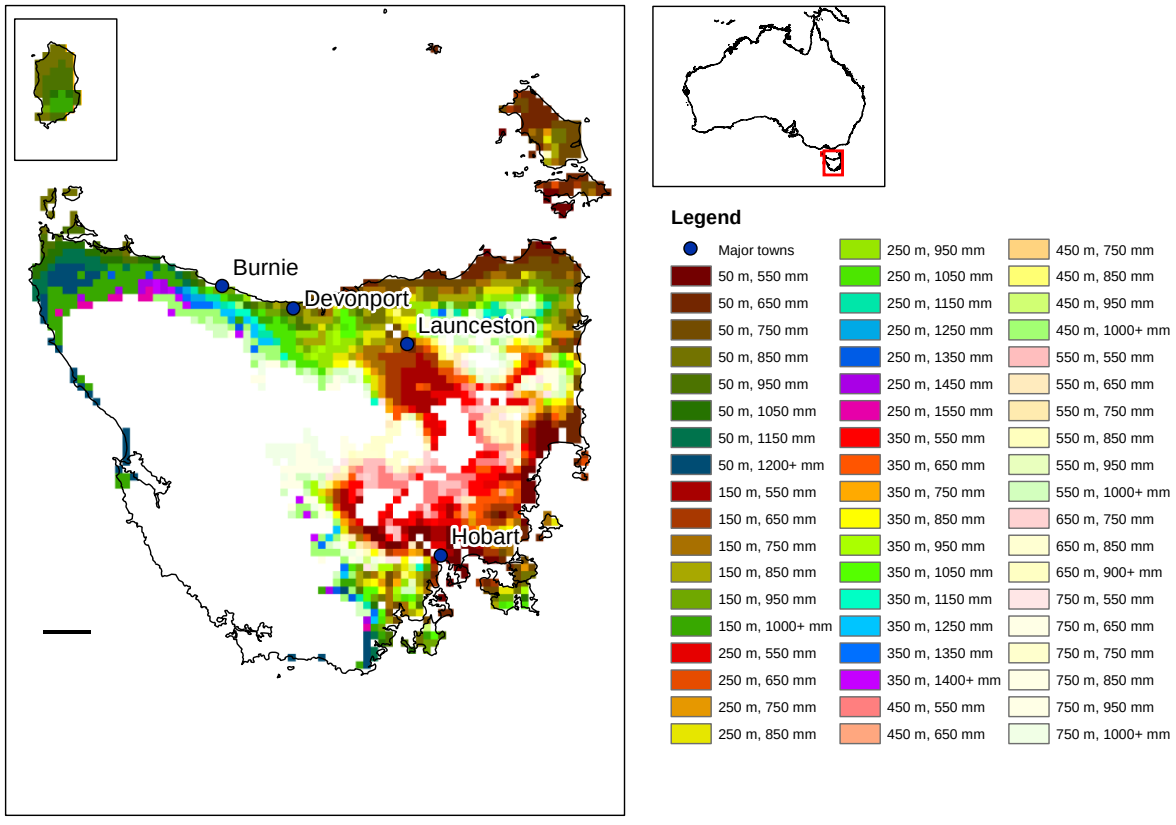

Legend
Major towns
550 mm rainfall, 1300 mm evaporation
550 mm rainfall, 1100 mm evaporation
650 mm rainfall, 1300 mm evaporation
650 mm rainfall, 1100 mm evaporation
650 mm rainfall, 900 mm evaporation
750 mm rainfall, 1300 mm evaporation
750 mm rainfall, 1100 mm evaporation
750 mm rainfall, 900 mm evaporation
850 mm rainfall, 1300 mm evaporation
850 mm rainfall, 1100 mm evaporation
850 mm rainfall, 900 mm evaporation
950 mm rainfall, 1300 mm evaporation
950 mm rainfall, 1100 mm evaporation
950 mm rainfall, 900 mm evaporation
1050 mm rainfall, 1300 mm evaporation
1050 mm rainfall, 1100 mm evaporation
1150 mm rainfall, 1300 mm evaporation
1150 mm rainfall, 1100 mm evaporation
1250 mm rainfall, 1300 mm evaporation
1250 mm rainfall, 1100 mm evaporation
1250 mm rainfall, 900 mm evaporation
1350 mm rainfall, 1300 mm evaporation
1350 mm rainfall, 1100 mm evaporation
1350 mm rainfall, 900 mm evaporation
1450 mm rainfall, 1100 mm evaporation
1450 mm rainfall, 900 mm evaporation
Melbourne
Sale
Morwell

Fig. 4 – FPOS climatic zones in Tasmania



The FPOS interface

The individual components of the interface are detailed below.

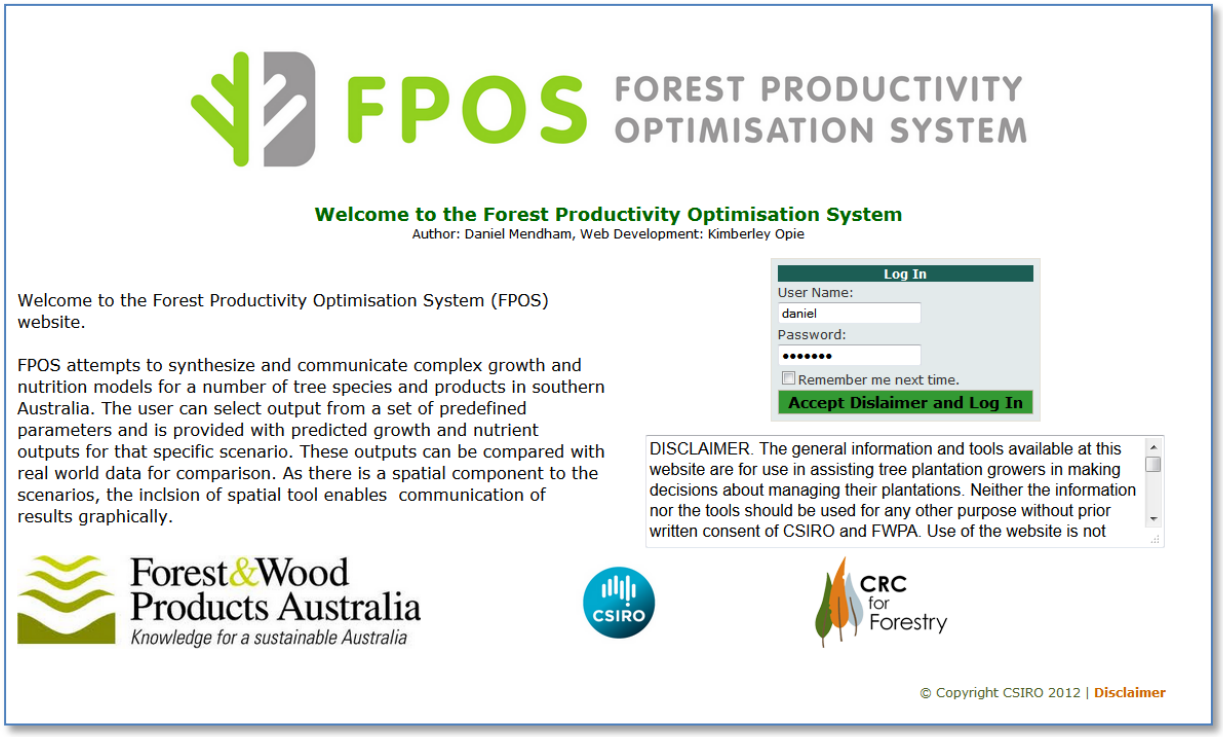
Login Page

The web address to access the system is:

https://www.crcforestrytools.com.au/fpos/login.aspx

The login page (Fig. 5) is the first page the user will have access to. The rest of the system is not available until the user logs in. Typically, logins are available at an organisational level, and any information that users enter into the system (site information, growth data, economic model) is only available to that login. The system is available to (1) members of the Forestry CRC, and (2) FWPA levy payers. If you fit into one of these categories and don't already have organisational access, please contact Daniel.Mendham@csiro.au for login details. Note that you need to accept the disclaimer in order to log into the system.

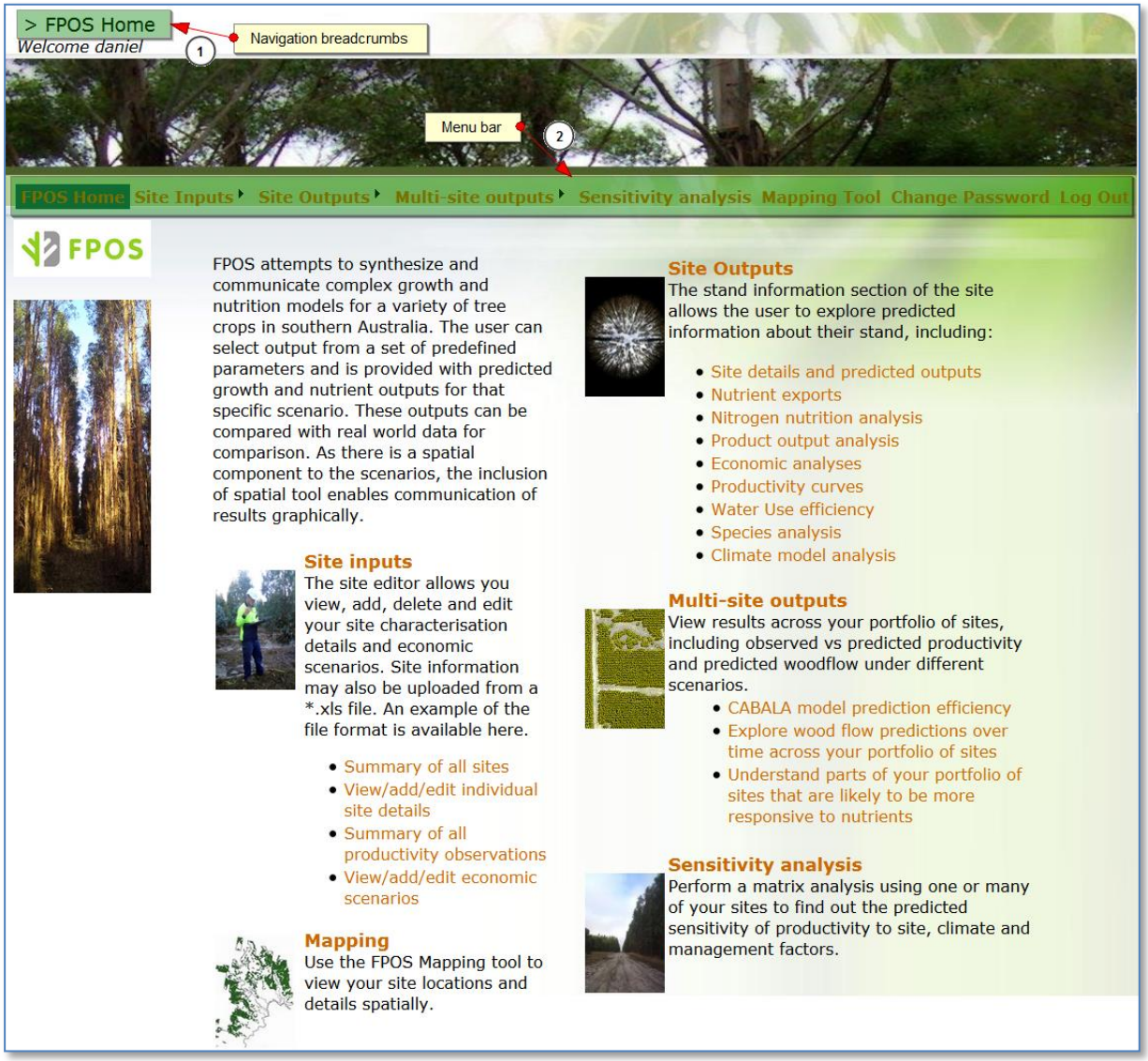
Fig. 5 – FPOS login page


FPOS
FOREST PRODUCTIVITY OPTIMISATION SYSTEM
Welcome to the Forest Productivity Optimisation System
Author: Daniel Mendham, Web Development: Kimberley Opie
Welcome to the Forest Productivity Optimisation System (FPOS) website.
FPOS attempts to synthesize and communicate complex growth and nutrition models for a number of tree species and products in southern Australia. The user can select output from a set of predefined parameters and is provided with predicted growth and nutrient outputs for that specific scenario. These outputs can be compared with real world data for comparison. As there is a spatial component to the scenarios, the inclsion of spatial tool enables communication of results graphically.
Log In
User Name:
daniel
Password:
Remember me next time.
Accept Dislaimer and Log In
DISCLAIMER. The general information and tools available at this website are for use in assisting tree plantation growers in making decisions about managing their plantations. Neither the information nor the tools should be used for any other purpose without prior written consent of CSIRO and FWPA. Use of the website is not
Forest&Wood Products Australia
Knowledge for a sustainable Australia
CSIRO
CRC for Forestry
© Copyright CSIRO 2012 | Disclaimer

Home Page

The home page (Fig. 6) has a brief description of each of the components of the system and hyperlinks to the rest of the system. The different sections of the system can also be accessed on any page via the menu bar (highlighted as item 2 in Fig. 6) at the top of the screen, and the current place within the system can be viewed by looking at the navigation breadcrumbs at the top of the screen (highlighted as item 1 in Fig. 6). The user can change their password to access the system through the 'change password' menu item.

Fig. 6 – The FPOS home screen. The navigation breadcrumbs (1) and menu bar (2) are highlighted.


> FPOS Home
Welcome daniel
1
Navigation breadcrumbs
Menu bar
2
FPOS Home
Site Inputs
Site Outputs
Multi-site outputs
Sensitivity analysis
Mapping Tool
Change Password
Log Out
FPOS
FPOS attempts to synthesize and communicate complex growth and nutrition models for a variety of tree crops in southern Australia. The user can select output from a set of predefined parameters and is provided with predicted growth and nutrient outputs for that specific scenario. These outputs can be compared with real world data for comparison. As there is a spatial component to the scenarios, the inclusion of spatial tool enables communication of results graphically.
Site inputs
The site editor allows you view, add, delete and edit your site characterisation details and economic scenarios. Site information may also be uploaded from a *.xls file. An example of the file format is available here.
Summary of all sites
View/add/edit individual site details
Summary of all productivity observations
View/add/edit economic scenarios
Mapping
Use the FPOS Mapping tool to view your site locations and details spatially.
Site Outputs
The stand information section of the site allows the user to explore predicted information about their stand, including:
Site details and predicted outputs
Nutrient exports
Nitrogen nutrition analysis
Product output analysis
Economic analyses
Productivity curves
Water Use efficiency
Species analysis
Climate model analysis
Multi-site outputs
View results across your portfolio of sites, including observed vs predicted productivity and predicted woodflow under different scenarios.
CABALA model prediction efficiency
Explore wood flow predictions over time across your portfolio of sites
Understand parts of your portfolio of sites that are likely to be more responsive to nutrients
Sensitivity analysis
Perform a matrix analysis using one or many of your sites to find out the predicted sensitivity of productivity to site, climate and management factors.

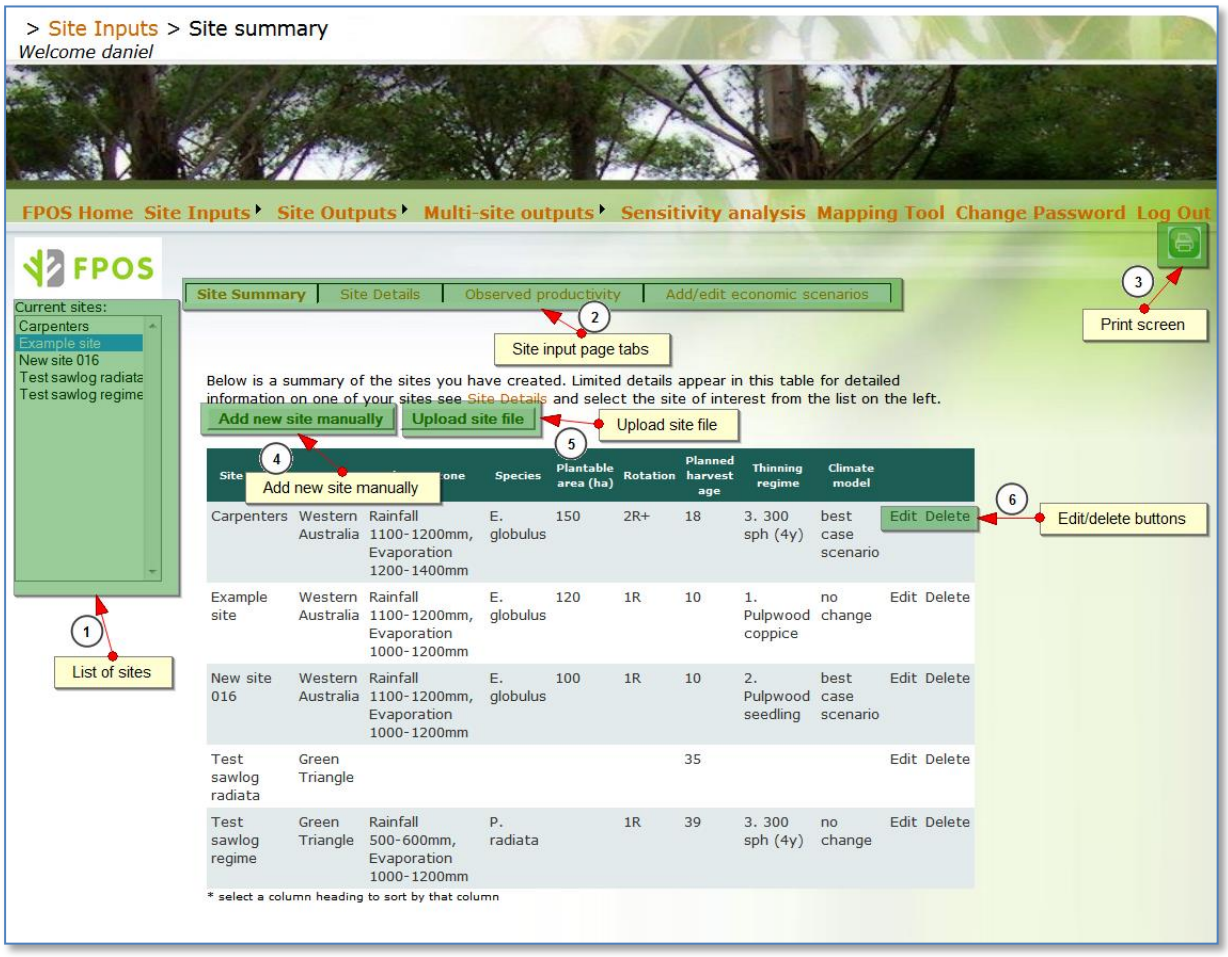
Site Inputs

The Site Input page consists of 4 tabs (Item 2, Fig. 7) – the Site Summary, Site Details, Observed productivity and Add/Edit economic scenario. The site-based pages also have a listing of the sites that have currently been entered through the existing login on the left hand site (Item 1, Fig. 7).

Site summary

The Site Summary page (Fig. 7) shows a listing of the sites that have currently been entered via the existing login, with the region, climatic zone, species, area, rotation, thinning regime and climate model for each scenario in the listing. Note that this list will only contain the example site initially (note that the example site is viewable by all logins, but cannot be edited). To add a new site manually, click 'Add new site manually' (Item 5, Fig. 7), or upload an excel file with your sites, click on this button (Item 6, Fig. 7). When you add a new site manually, a new, blank site (named 'New Site XXX', where XXX is the next number in the sequence, starting with 001 and incrementing) appears in the list which can be edited directly. To edit or delete an individual site, you can enter the 'site details' tab (see Item 2, Fig. 7), or click on the edit or delete buttons for each site (Item 6, Fig. 7). Also highlighted on this screen shot is the 'print screen' icon (Item 6, Fig. 3), which extracts the page in PDF format for printing or saving.

Fig. 7 – Site Inputs/Site Summary page. Highlighted areas are 1. Site listing panel, 2. Site input page tabs, and 3. Print screen icon, 4. Add new site button, 5. Upload site file button, 6. Site edit and delete buttons.


> Site Inputs > Site summary
Welcome daniel
FPOS Home Site Inputs Site Outputs Multi-site outputs Sensitivity analysis Mapping Tool Change Password Log Out
FPOS
Current sites:
Carpenters
Example site
New site 016
Test sawlog radiata
Test sawlog regime
Site Summary
Site Details
Observed productivity
Add/edit economic scenarios
2
Site input page tabs
3
Print screen
Below is a summary of the sites you have created. Limited details appear in this table for detailed information on one of your sites see Site Details and select the site of interest from the list on the left.
Add new site manually
Upload site file
Upload site file
4
Add new site manually
5
6
Edit/delete buttons
1
List of sites
Site
Species
Plantable area (ha)
Rotation
Planned harvest age
Thinning regime
Climate model
Carpenters Western Australia Rainfall 1100-1200mm, Evaporation 1200-1400mm E. globulus 150 2R+ 18 3. 300 sph (4y) best case scenario Edit Delete
Example site Western Australia Rainfall 1100-1200mm, Evaporation 1000-1200mm E. globulus 120 1R 10 1. Pulpwood coppice no change Edit Delete
New site 016 Western Australia Rainfall 1100-1200mm, Evaporation 1000-1200mm E. globulus 100 1R 10 2. Pulpwood seedling best case scenario Edit Delete
Test sawlog radiata Green Triangle 35 Edit Delete
Test sawlog regime Green Triangle Rainfall 500-600mm, Evaporation 1000-1200mm P. radiata 1R 39 3. 300 sph (4y) no change Edit Delete
* select a column heading to sort by that column

Site Details

The site details page (Fig. 8) allows the user to view and/or edit the details of each of their sites/scenarios. The buttons at the top (highlighted 1-4, Fig. 8) allow the user to add, upload, edit or delete the current site. Some of the inputs for each site are essential (shown with asterisks) for the model to run adequately, while others are required for other parts of the system and/or for information only. The key inputs are as follows:

\

Site name: is used to identify the site

Latitude and Longitude: These are optional inputs, but if you enter values the system will attempt to identify the appropriate Region and Climatic zone. Note that you can override the systems choice if you feel that it has not characterised your region/climatic zone appropriately. This is probably more important for the regions where climatic zone is based on altitude (Tasmania) as the altitude grid is reasonably coarse.

Exposed site: This check-box allows the user to choose whether the site is exposed. The effects of exposure have not been fully quantified, so the system currently deals with exposed sites in Tasmania by changing the climatic zone to increase the altitude by 1 level (eg. an exposed site at 200-300 m altitude will instead draw its results from a 300-400 m altitude site with the same rainfall). In Eastern Victoria the exposed site effect is created by drawing the results from a lower evaporation zone (which is also linked to altitude). The 'exposed site' option is not applicable in WA or the GT. This input is optional, with non-exposed being the default option.

Rainfall variation: This is a required input for CABALA, and it allows the user to explore different rainfall variation that may occur within a climate prediction, and is based on running 10-year averages for the 30-year period of the climate model (either 1975-2005 for the existing model, or 2015-2045 for the future scenarios). The average monthly climate is used for each climatic zone, and only rainfall is varied as follows:

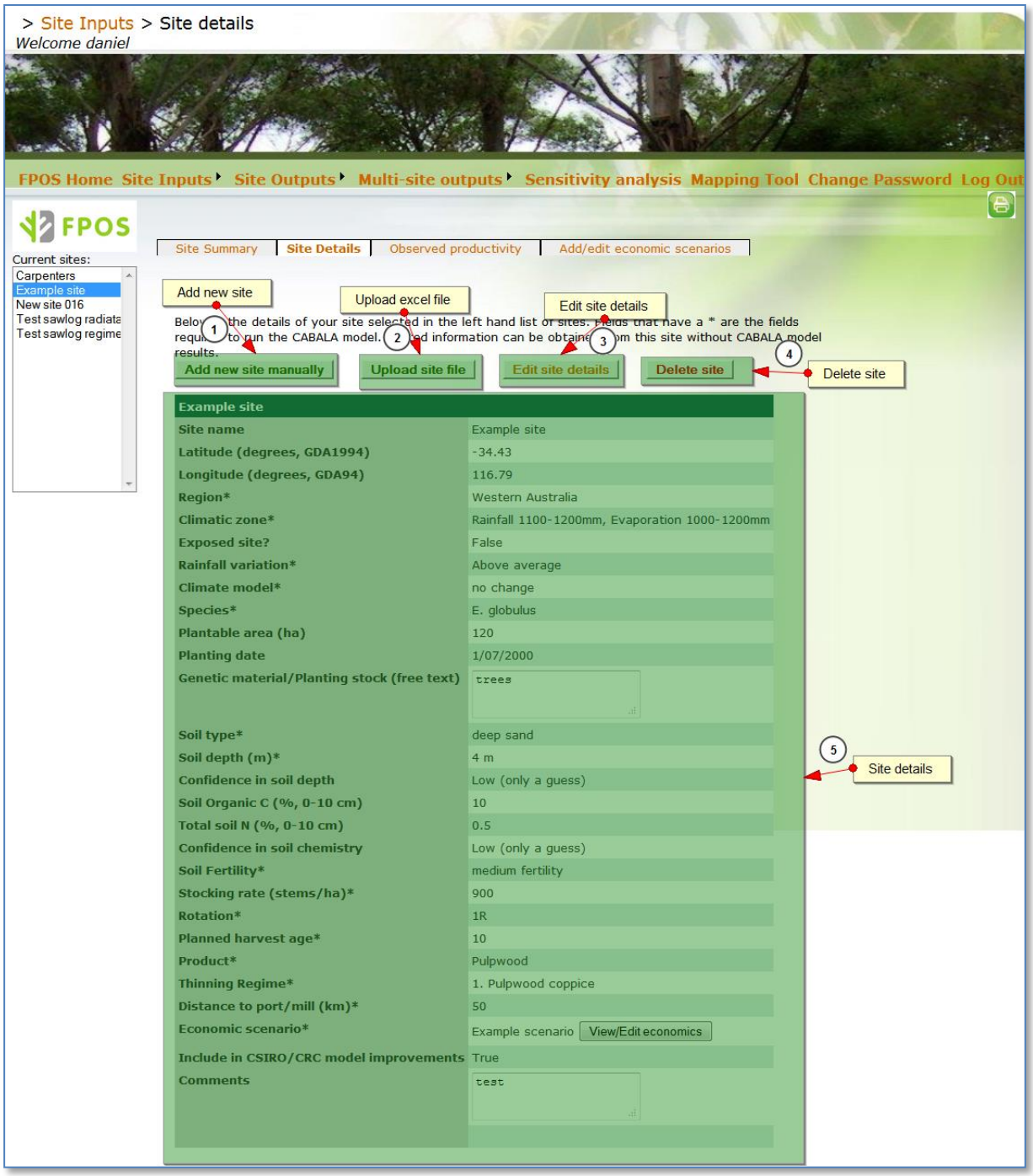
- Well below average is the mean monthly rainfall less 2 standard deviations
- Below average is the mean monthly rainfall less 1 standard deviation
- Average is the mean monthly rainfall
- Above average is the mean monthly rainfall plus 1 standard deviation
- Well above average is the mean monthly rainfall plus 2 standard deviations

Climate model: This menu has 4 options, no change (based on historical data from 1975-2005), best case scenario (based on the climate model with the highest rainfall prediction for the future), worst case scenario (based on the climate model with the lowest rainfall prediction for the future), and the most likely scenario, which is based on the model that predicts the median rainfall among the group of climate models used in the study. These models are different for each region (see section on climate models above). This input is required by CABALA to produce any output for a scenario.

Species: This menu allows the user to choose from the 5 species available in FPOS (*E. globulus*, *E. nitens*, *E. smithii*, *P. pinaster*, *P. radiata*). This input is required by CABALA to produce any output.

PlanTable area and Planting date: are both optional inputs, and are only required if you are interested in estimating potential wood flow across your estate under different rainfall or climate model. Note that planting date is only used for calculating wood flow, not for calculating yield at any given site and it doesn't account for the effects of planting at different times of the year.

Fig. 8 – The site details page, showing 1. 'add new site' button, 2. 'Upload site file' button, 3. 'Edit site details' button, 4. 'Delete site' button, and 5. The details pane highlighted.



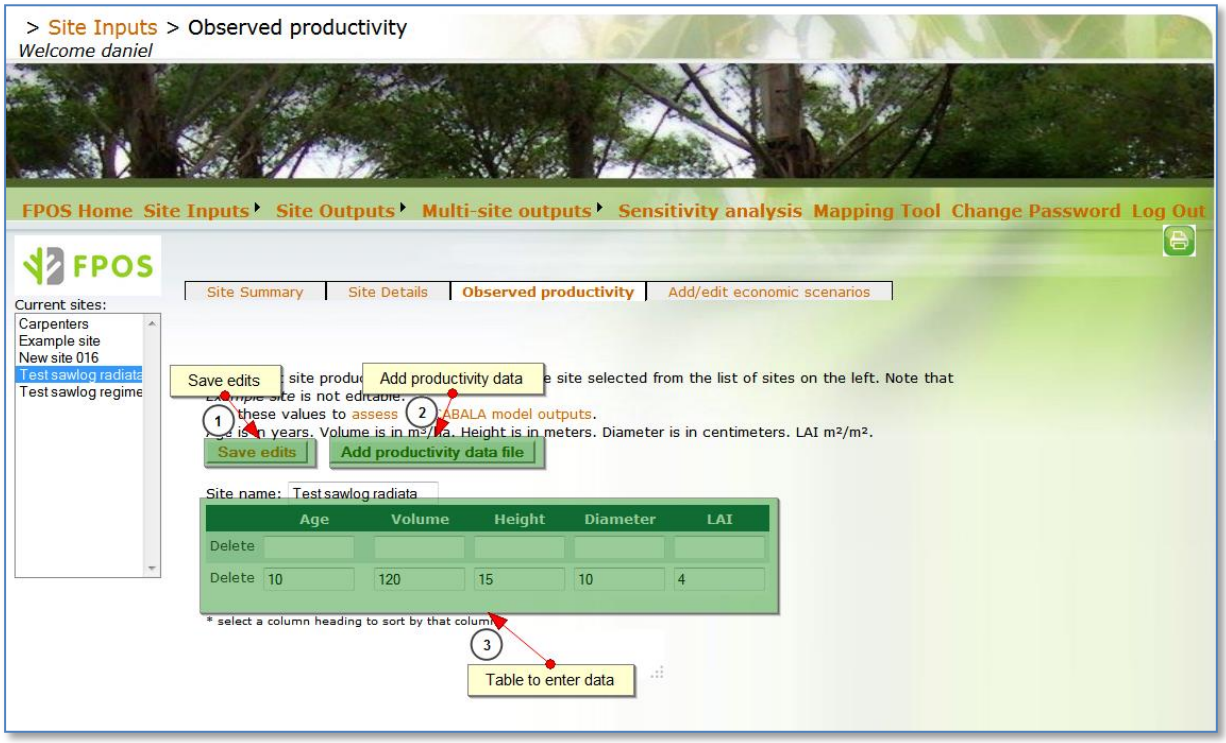
Genetic material/planting stock: This information is not used by the system, but is there to allow the user to make notes for their own use about any particular scenario.
Soil type: This is a required input for CABALA. The soil types a user can select is dependent on the climatic zone, and there are typically 2-3 soils available within any given climatic zone. The main attribute of soil type that is used by the system is the water holding capacity of the soil as soil fertility is a separate input.
Soil depth: This is a required input for CABALA, and the options change depending on the climatic zone that is chosen. The available soils in WA and the Green Triangle tend to be deeper than those that are available in Tasmania and Victoria.
Soil organic C and total N (0-10 cm): are optional inputs, but are intended to help the user to classify their soil fertility. If the user has a good feel for their soil fertility they can skip

directly to that input and not worry about selecting a C or N value. Alternatively, if they choose C and N values and are not happy with the fertility rating that the system chooses they are welcome to override the system choice.
Soil Fertility: is a required input for CABALA, from high fertility (which is intended to represent an ex-pasture site with a good fertilizer history), through to low fertility (which is intended to represent an ex-bush site with no fertilizer history).
Stocking rate: is a required input for CABALA, with the user able to select a value from 600 stems/ha to 2000 stems/ha, in 100 stems/ha increments.
Rotation: is a required input for the interface, with users able to choose from first rotation, or 2nd rotation (or later) seedling (all species) or coppice (*E. globulus* and *E. smithii*)
Planned harvest age: is a required input for the interface, with users able to choose any age up to 20 for a pulpwood regime, or any age up to 40 for a sawlog regime.
Product: is a required input for the interface, with users able to choose from sawlogs or pulpwood. Note that the product choice influences the potential rotation length
Thinning regime: Is a required input for the interface. The available options are dependent on the species chosen, with different thinning regimes available for softwood and hardwood species (approximately 15 for each). Note that each regime has a unique number so you can easily find your preferred regime from the list once you have found some regimes in the list that you want to work with.
Distance to port/mill: Is a required input for the economics module. Note that the system will attempt to calculate a distance to the nearest port if the user enters latitude/longitude coordinates. This is a simple algorithm that calculates a direct as-the-crow-flies distance and adds a 20% tortuosity factor.
Economic scenario: is a required input for the economics module. The user can enter as many economic scenarios as they wish. An example scenario is included for demonstration purposes, but it should not be relied upon for your specific circumstances.
Comments: provides the user with an option to enter any comments or remarks about the particular scenario
Include in CSIRO/CRC model improvements: This option is to allow your data to feed back into future model improvements. Note that we will not release individual site information or be looking at any of the economic information. This is about trying to understand where the model is working well and where it could use future improvement. The inputs regarding 'confidence' in soil chemistry and soil depth information are used in this regard as we will not be able to use data for future model improvements unless the sites have been well characterised.

Observed Productivity tab

The Observed Productivity tab allows the user to enter their own site information. This data is shown on the model output graphs so that the user can see how closely the model is representing their observed productivity. The data can also be used to compare model performance across several sites under the 'Multi-site output' menu option. Data can be entered manually through the interface, or it can be uploaded via an Excel spreadsheet file. To enter data manually, type values into the empty boxes in the data entry table (Item 3, Fig. 9), and save the edits (Item 1, Fig. 9). Upon saving a new blank row will appear to allow the user to enter another measurement if it is available.

Fig. 9 – Observed productivity tab, showing (1) the 'Save edits' button, (2) the 'Load from File' button, and (3) the data entry table.

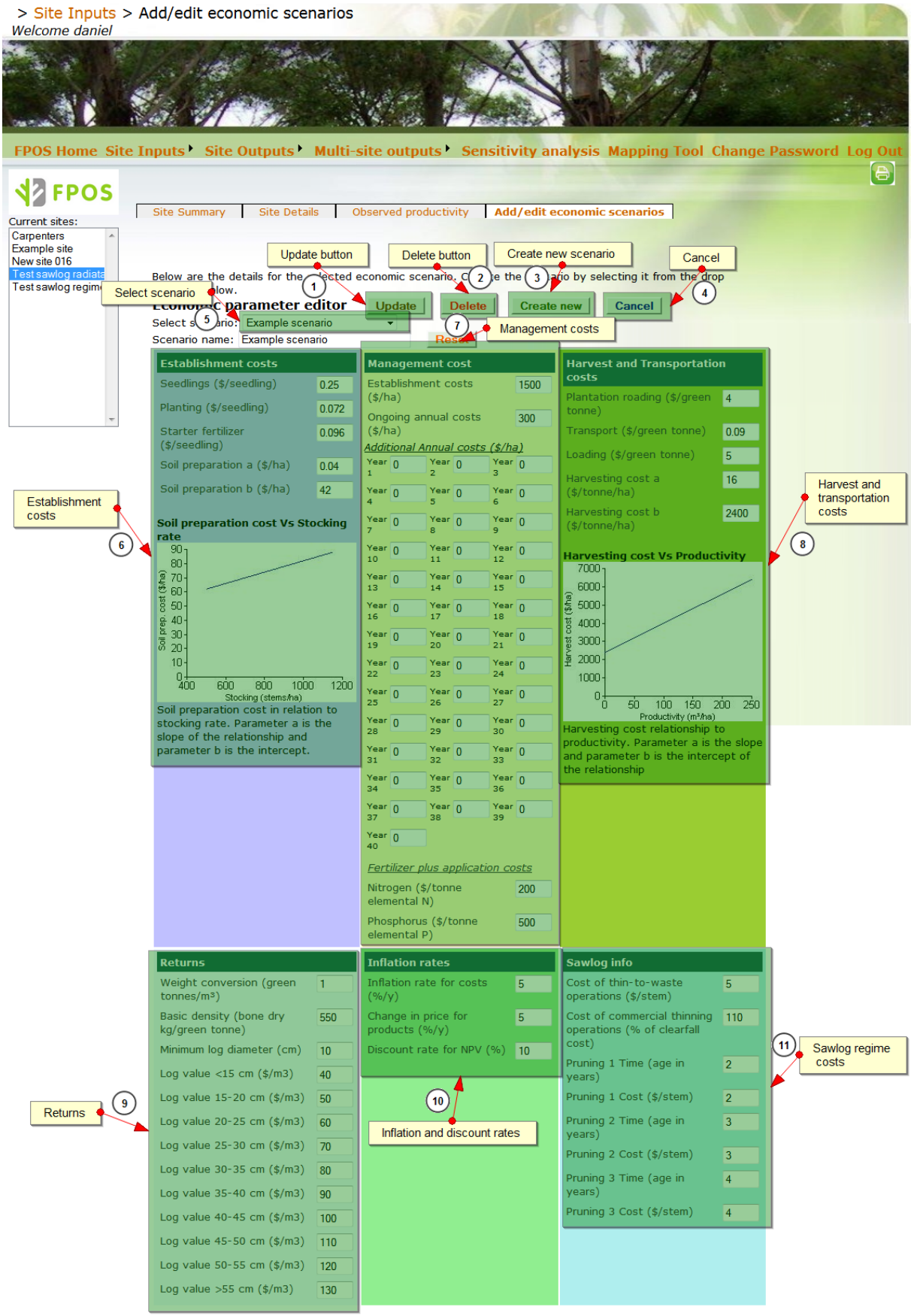


Add/edit economic scenarios tab

This tab allows the user to create and/or modify their economic scenarios. The example scenario is provided as a starting point, but will need to be modified appropriately. A scenario can be selected from the pull-down menu (Item 5, Fig. 10). A new scenario can be created by clicking on the 'new scenario' button (Item 3, Fig. 10), which copies the values from the scenario that is currently selected into a new scenario. The inputs are grouped into 6 different costs and returns categories as follows:

1. Establishment costs (Item 6, Fig. 10), which include per seedling-based prices (seedling price, planting price, and starter fertilizer), and area based costs for soil preparation. Note that soil preparation cost is based on a linear relationship between stocking and cost, where the 'a' parameter is the slope of the relationship, and the 'b' parameter is the intercept. If the land preparation cost does not vary with stocking, you can set the 'a' value to zero. The graph shows the relationship between stocking and soil preparation cost as defined by the function.

Fig. 10 – Add/edit economic scenarios tab. Highlighted items are described in the text


> Site Inputs > Add/edit economic scenarios
Welcome daniel
FPOS Home Site Inputs Site Outputs Multi-site outputs Sensitivity analysis Mapping Tool Change Password Log Out
FPOS
Site Summary Site Details Observed productivity Add/edit economic scenarios
Current sites:
Carpenters
Example site
New site 016
Test sawlog radiata
Test sawlog regim
Update button
Delete button
Create new scenario
Cancel
Select scenario
Below are the details for the selected economic scenario. Create the scenario by selecting it from the drop
Economic parameter editor
Update
Delete
Create new
Cancel
Select scenario: Example scenario
Scenario name: Example scenario
Reset
Management costs
Establishment costs
Seedlings ($/seedling) 0.25
Planting ($/seedling) 0.072
Starter fertilizer ($/seedling) 0.096
Soil preparation a ($/ha) 0.04
Soil preparation b ($/ha) 42
Soil preparation cost Vs Stocking rate
Soil prep. cost ($/ha)
Stocking (stems/ha)
Soil preparation cost in relation to stocking rate. Parameter a is the slope of the relationship and parameter b is the intercept.
Management cost
Establishment costs ($/ha) 1500
Ongoing annual costs ($/ha) 300
Additional Annual costs ($/ha)
Fertilizer plus application costs
Nitrogen ($/tonne elemental N) 200
Phosphorus ($/tonne elemental P) 500
Harvest and Transportation costs
Plantation roading ($/green tonne) 4
Transport ($/green tonne) 0.09
Loading ($/green tonne) 5
Harvesting cost a ($/tonne/ha) 16
Harvesting cost b ($/tonne/ha) 2400
Harvesting cost Vs Productivity
Harvest cost ($/ha)
Productivity (m³/ha)
Harvesting cost relationship to productivity. Parameter a is the slope and parameter b is the intercept of the relationship
Establishment costs
Harvest and transportation costs
Returns
Weight conversion (green tonnes/m³) 1
Basic density (bone dry kg/green tonne) 550
Minimum log diameter (cm) 10
Log value <15 cm ($/m3) 40
Log value 15-20 cm ($/m3) 50
Log value 20-25 cm ($/m3) 60
Log value 25-30 cm ($/m3) 70
Log value 30-35 cm ($/m3) 80
Log value 35-40 cm ($/m3) 90
Log value 40-45 cm ($/m3) 100
Log value 45-50 cm ($/m3) 110
Log value 50-55 cm ($/m3) 120
Log value >55 cm ($/m3) 130
Inflation rates
Inflation rate for costs (%/y) 5
Change in price for products (%/y) 5
Discount rate for NPV (%) 10
Inflation and discount rates
Sawlog info
Cost of thin-to-waste operations ($/stem) 5
Cost of commercial thinning operations (% of clearfall cost) 110
Pruning 1 Time (age in years) 2
Pruning 1 Cost ($/stem) 2
Pruning 2 Time (age in years) 3
Pruning 2 Cost ($/stem) 3
Pruning 3 Time (age in years) 4
Pruning 3 Cost ($/stem) 4
Sawlog regime costs
Returns
1
2
3
4
5
6
7
8
9
10
11

2. Management costs (Item 7, Fig. 10), which include other area-based establishment costs not already accounted for and ongoing annual costs (which may include land

lease costs, management fees etc.). The fixed annual costs can be entered at the top, and any annual costs that vary during the rotation can be entered separately for each year. Enter the costs in todays dollar values. The user can also enter fertilizer costs here.

3. Harvest and transportation costs (Item 8, Fig. 10), include costs that are based on tonnes of timber harvested (roading, transportation and loading costs), and harvesting cost is on an area basis. Harvesting cost can vary with the productivity by adjusting the harvesting cost 'a' (slope) and 'b' (intercept) parameters. This operates the same way as the establishment costs in that a constant harvesting cost can be set if desired by setting the 'a' parameter to zero.
4. Returns (Item 9, Fig. 10) include the value for different size logs in 5 cm increments from 15 cm to 55 cm, the minimum log diameter, and the weight conversion and basic density.
5. Inflation rates (Item 10, Fig. 10) can be set individually for costs and prices, and the discount rate (as used in NPV calculations) can be set here too.
6. Sawlog information (Item 11, Fig. 10) allows the user to enter information about the cost of thin-to-waste operations on a stem basis, the cost of commercial thinning operations as a percentage of clearfall costs (as defined in the 'Harvest and Transportation costs'), and the cost of pruning. Note that pruning does not affect growth or estimates of sawlog recovery, but is only used in the economic calculations.

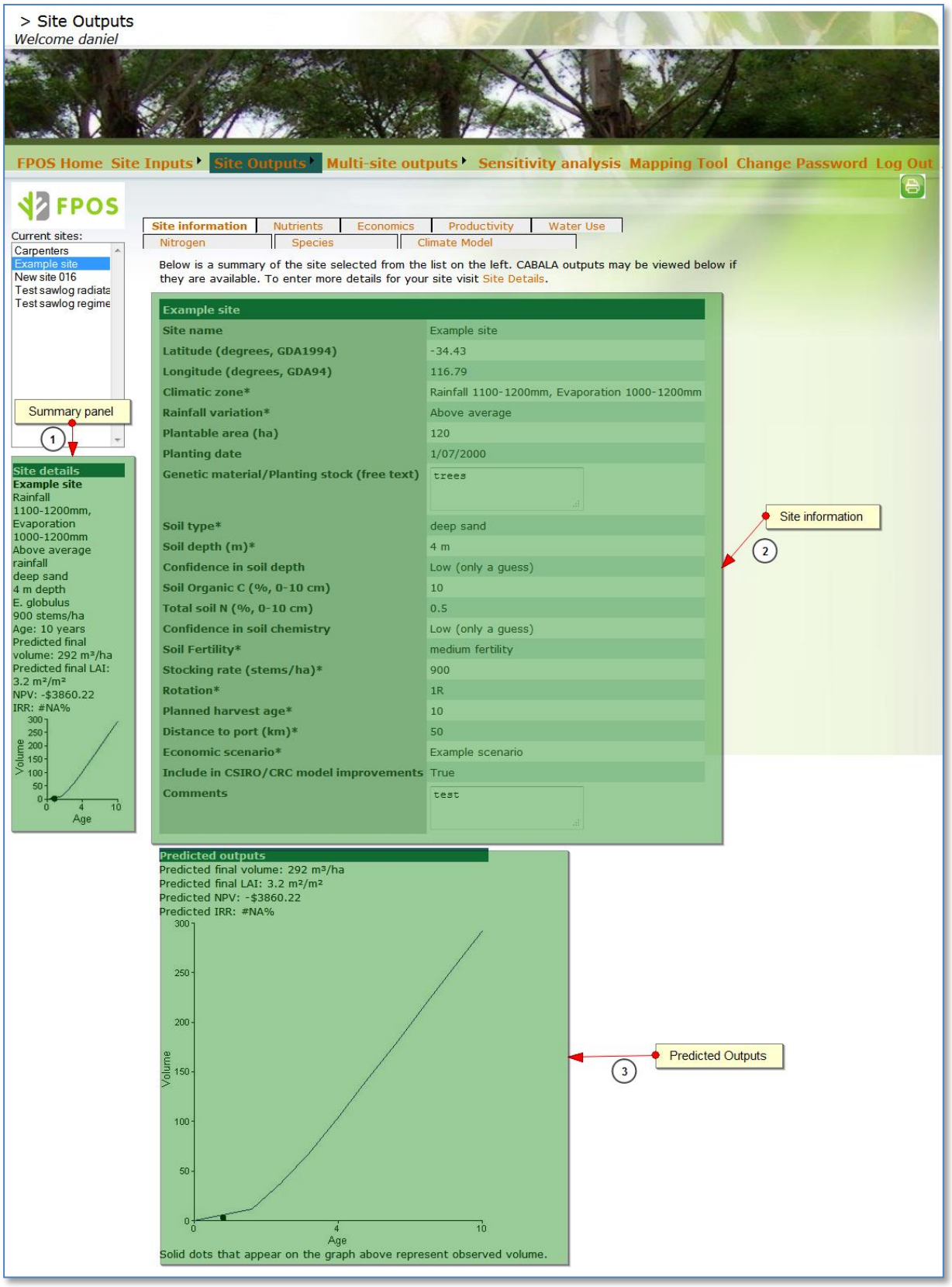
Site Outputs

The Site Outputs page has 8 tabs, including Site Information, Nutrients, Economics, Productivity, Water Use, Nitrogen, Species, and Climate Model. This is where the majority of the model output can be retrieved for individual sites.

Site Information

Each page within the Site Outputs menu shows a summary of the scenario outputs on the left hand side (Item 1, Fig. 11), including the selected climatic zone, rainfall variation, soil type and depth, stocking rate and harvest age, along with the predicted final volume, final LAI, as well as the NPV and IRR. A thumbnail graph of the predicted volume growth is shown as well, with observed data as points and model predicted productivity as a line on the graph. Note that the IRR is calculated using a solving function which is not able to find a solution if the IRR is too low. If this is the case, the IRR is shown as '#NA'. The predicted outputs are also shown in larger format at the bottom of the 'Site Information' tab (Item 3, Fig. 11), along with the scenario details (Item 2, Fig. 11).

Fig. 11 – Site Information tab, highlighting (1) the Summary output panel, (2) the Site information, and (3) the predicted outputs



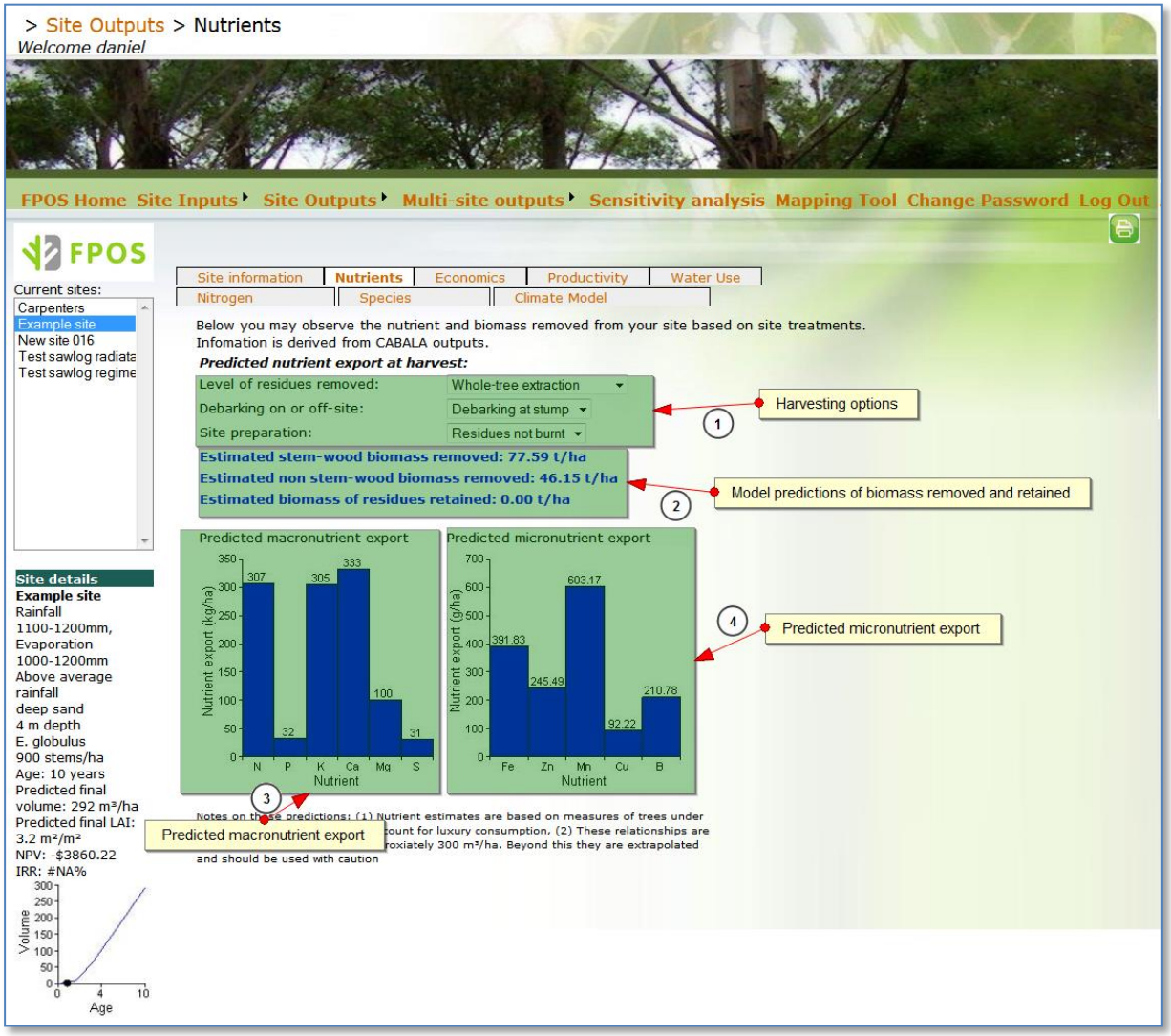
Nutrients

The Nutrients tab allows the user to explore the impacts of different harvesting options on export of biomass and nutrients from the site. This information is based on the quantity of nutrients in each of the biomass fractions, so is subject to some error where there has been significant luxury uptake of nutrients, or the biomass split between components is different at a given site to the values used in the FPOS system. The options for levels of residues removed are:

- Whole tree extraction – meaning that the trees are cut at the base and removed from the site without debarking or debranching.
- Residues retained on site

If residues are retained on site, the user needs to select whether the bark is removed on site or off site. If the bark is removed at a landing it should be considered to be off-site unless it is redistributed back across the site. The user also needs to choose whether the residues are burnt or not burnt, as burning will result in loss of much of the volatile nutrients.

Fig. 12 – Nutrient export tab, highlighting (1) harvesting options, (2) predicted biomass removed and retained, (3) the predicted macronutrient export, and (4) the predicted micronutrient export.



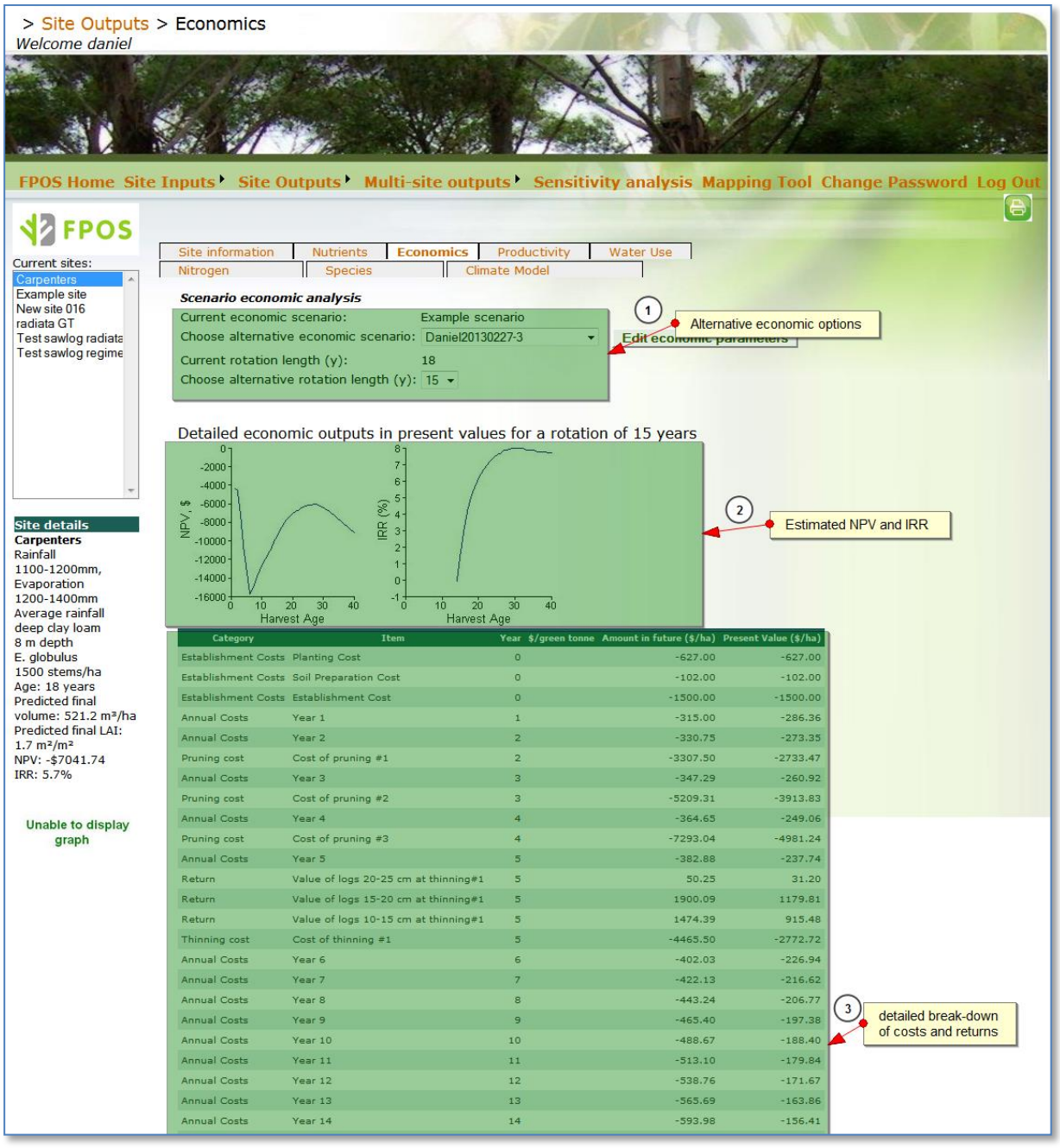
The system estimates the biomass removed in stem wood and non-stem wood components, and also the amount retained on site (Item 2, Fig. 12), and shows a graph of the predicted macronutrient export (Item 3, Fig. 12) in kg/ha, and the predicted micronutrient export (Item

4, Fig. 12), in g/ha. The export data for *Eucalyptus* species are based on our own studies with *E. globulus* in Western Australia, whilst the export data for *Pinus* species are based on the study of Hopman and Elms (2009).

Economics

The economics tab allows the user to look in detail at the itemised costs and returns of the chosen scenario. This tab allows the user to compare the effect of different economic models and/or different rotation lengths through 2 pull-down menus (Item 1, Fig. 13). There is also a link to edit the economic model if the users want to. The graphs on this tab (Item 2, Fig. 13) show the potential net present values and internal rates of return that the model predicts for the full range of potential harvest ages. This allows the user to explore the optimum rotation length. The table below the graphs (Item 3, Fig. 13) has a detailed listing of the costs and returns associated with the harvest age that is chosen in the pull-down menu in Item 1, Fig. 13.

Fig. 13 – The Economics tab, highlighting the (1) Alternative economic scenario options, (2) estimated NPV and IRR, and (3) a detailed break-down of costs and returns

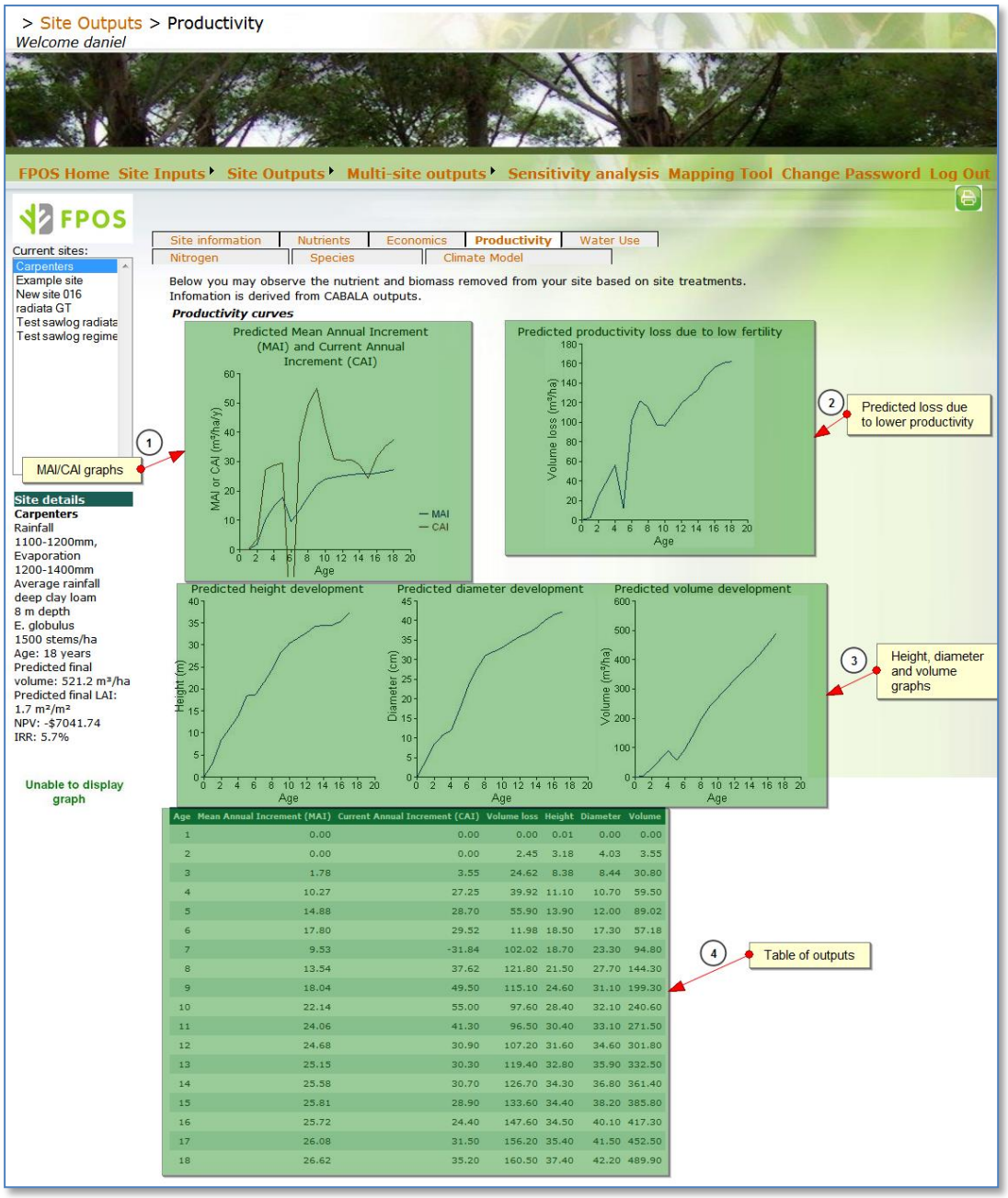

> Site Outputs > Economics
Welcome daniel
FPOS Home Site Inputs Site Outputs Multi-site outputs Sensitivity analysis Mapping Tool Change Password Log Out
FPOS
Site information Nutrients Economics Productivity Water Use
Nitrogen Species Climate Model
Current sites:
Carpenters
Example site
New site 016
radiata GT
Test sawlog radiata
Test sawlog regime
Scenario economic analysis
Current economic scenario: Example scenario
Choose alternative economic scenario: Daniel20130227-3
Current rotation length (y): 18
Choose alternative rotation length (y): 15
1
Alternative economic options
Edit economic parameters
Detailed economic outputs in present values for a rotation of 15 years
NPV, $
IRR (%)
Harvest Age
Harvest Age
2
Estimated NPV and IRR
Site details
Carpenters
Rainfall 1100-1200mm, Evaporation 1200-1400mm
Average rainfall deep clay loam 8 m depth
E. globulus 1500 stems/ha
Age: 18 years
Predicted final volume: 521.2 m³/ha
Predicted final LAI: 1.7 m²/m²
NPV: -$7041.74
IRR: 5.7%
Unable to display graph
Category Item Year $/green tonne Amount in future ($/ha) Present Value ($/ha)
Establishment Costs Planting Cost 0 -627.00 -627.00
Establishment Costs Soil Preparation Cost 0 -102.00 -102.00
Establishment Costs Establishment Cost 0 -1500.00 -1500.00
Annual Costs Year 1 1 -315.00 -286.36
Annual Costs Year 2 2 -330.75 -273.35
Pruning cost Cost of pruning #1 2 -3307.50 -2733.47
Annual Costs Year 3 3 -347.29 -260.92
Pruning cost Cost of pruning #2 3 -5209.31 -3913.83
Annual Costs Year 4 4 -364.65 -249.06
Pruning cost Cost of pruning #3 4 -7293.04 -4981.24
Annual Costs Year 5 5 -382.88 -237.74
Return Value of logs 20-25 cm at thinning#1 5 50.25 31.20
Return Value of logs 15-20 cm at thinning#1 5 1900.09 1179.81
Return Value of logs 10-15 cm at thinning#1 5 1474.39 915.48
Thinning cost Cost of thinning #1 5 -4465.50 -2772.72
Annual Costs Year 6 6 -402.03 -226.94
Annual Costs Year 7 7 -422.13 -216.62
Annual Costs Year 8 8 -443.24 -206.77
Annual Costs Year 9 9 -465.40 -197.38
Annual Costs Year 10 10 -488.67 -188.40
Annual Costs Year 11 11 -513.10 -179.84
Annual Costs Year 12 12 -538.76 -171.67
Annual Costs Year 13 13 -565.69 -163.86
Annual Costs Year 14 14 -593.98 -156.41
3
detailed break-down of costs and returns

Productivity

The productivity tab allows the user to explore the predicted productivity, including:

- MAI and CAI curves (Item 1, Fig. 14). The example in Fig. 14 exhibits a negative CAI and reduced MAI in year 6, associated with a thinning event, followed by a rapid increase in CAI.
- The predicted loss in productivity due to lower than optimum fertility (Item 2, Fig. 14) is calculated as the difference between the model output for maximum soil fertility and the model output for the chosen soil fertility scenario. If the maximum fertility is chosen then there will be no predicted productivity loss due to lower fertility.
- The development of height, diameter and volume are also shown in graphical form (Item 3, Fig. 14), and in tabular form (Item 4, Fig. 14).

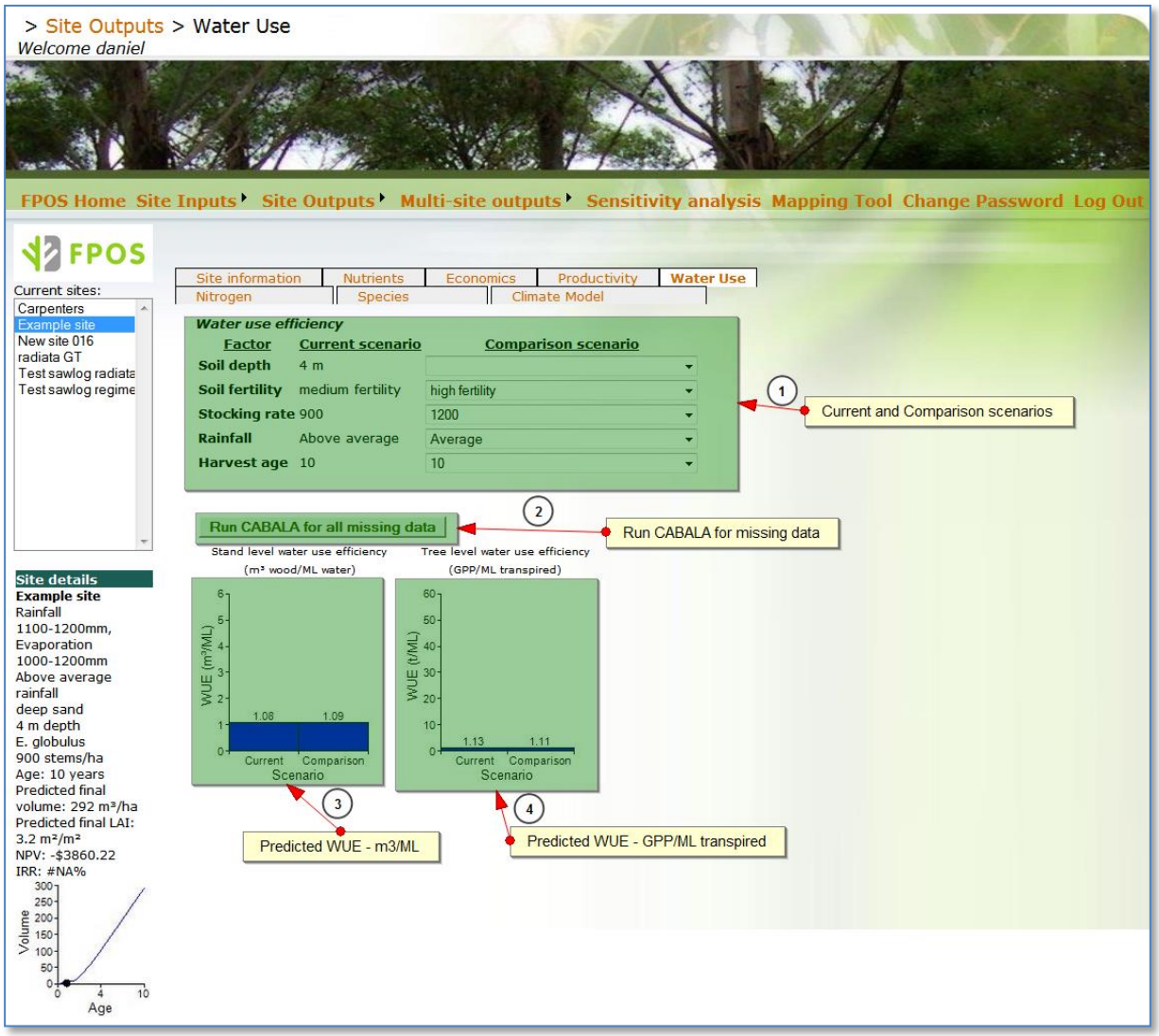
Fig. 14 – Productivity tab, with (1) CAI/MAI curves highlighted, (2) predicted losses due to lower fertility, (3) height, diameter and volume curves, and (4) tabulated outputs highlighted.


> Site Outputs > Productivity
Welcome daniel
FPOS Home Site Inputs Site Outputs Multi-site outputs Sensitivity analysis Mapping Tool Change Password Log Out
FPOS
Site information Nutrients Economics Productivity Water Use
Nitrogen Species Climate Model
Current sites:
Carpenters
Example site
New site 016
radiata GT
Test sawlog radiata
Test sawlog regime
Below you may observe the nutrient and biomass removed from your site based on site treatments.
Infomation is derived from CABALA outputs.
Productivity curves
Predicted Mean Annual Increment (MAI) and Current Annual Increment (CAI)
MAI or CAI (m³/ha/y)
Age
MAI
CAI
Predicted productivity loss due to low fertility
Volume loss (m³/ha)
Age
1
MAI/CAI graphs
2
Predicted loss due to lower productivity
Site details
Carpenters
Rainfall 1100-1200mm,
Evaporation 1200-1400mm
Average rainfall deep clay loam
8 m depth
E. globulus
1500 stems/ha
Age: 18 years
Predicted final volume: 521.2 m³/ha
Predicted final LAI: 1.7 m²/m²
NPV: -$7041.74
IRR: 5.7%
Unable to display graph
Predicted height development
Height (m)
Predicted diameter development
Diameter (cm)
Predicted volume development
Volume (m³/ha)
3
Height, diameter and volume graphs
Age Mean Annual Increment (MAI) Current Annual Increment (CAI) Volume loss Height Diameter Volume
1 0.00 0.00 0.00 0.01 0.00 0.00
2 0.00 0.00 2.45 3.18 4.03 3.55
3 1.78 3.55 24.62 8.38 8.44 30.80
4 10.27 27.25 39.92 11.10 10.70 59.50
5 14.88 28.70 55.90 13.90 12.00 89.02
6 17.80 29.52 11.98 18.50 17.30 57.18
7 9.53 -31.84 102.02 18.70 23.30 94.80
8 13.54 37.62 121.80 21.50 27.70 144.30
9 18.04 49.50 115.10 24.60 31.10 199.30
10 22.14 55.00 97.60 28.40 32.10 240.60
11 24.06 41.30 96.50 30.40 33.10 271.50
12 24.68 30.90 107.20 31.60 34.60 301.80
13 25.15 30.30 119.40 32.80 35.90 332.50
14 25.58 30.70 126.70 34.30 36.80 361.40
15 25.81 28.90 133.60 34.40 38.20 385.80
16 25.72 24.40 147.60 34.50 40.10 417.30
17 26.08 31.50 156.20 35.40 41.50 452.50
18 26.62 35.20 160.50 37.40 42.20 489.90
4
Table of outputs

Water Use

The water use tab is to allow the user to understand the water use efficiency of a given scenario, and to compare this with an alternative scenario. Alternative scenarios can include different soil depths, soil fertility, stocking rate, rainfall and/or harvest age. The alternative scenario can be selected by choosing different options in the comparison scenario pull-down menus (Item 1, Fig. 15). The combination of all possible alternative scenarios

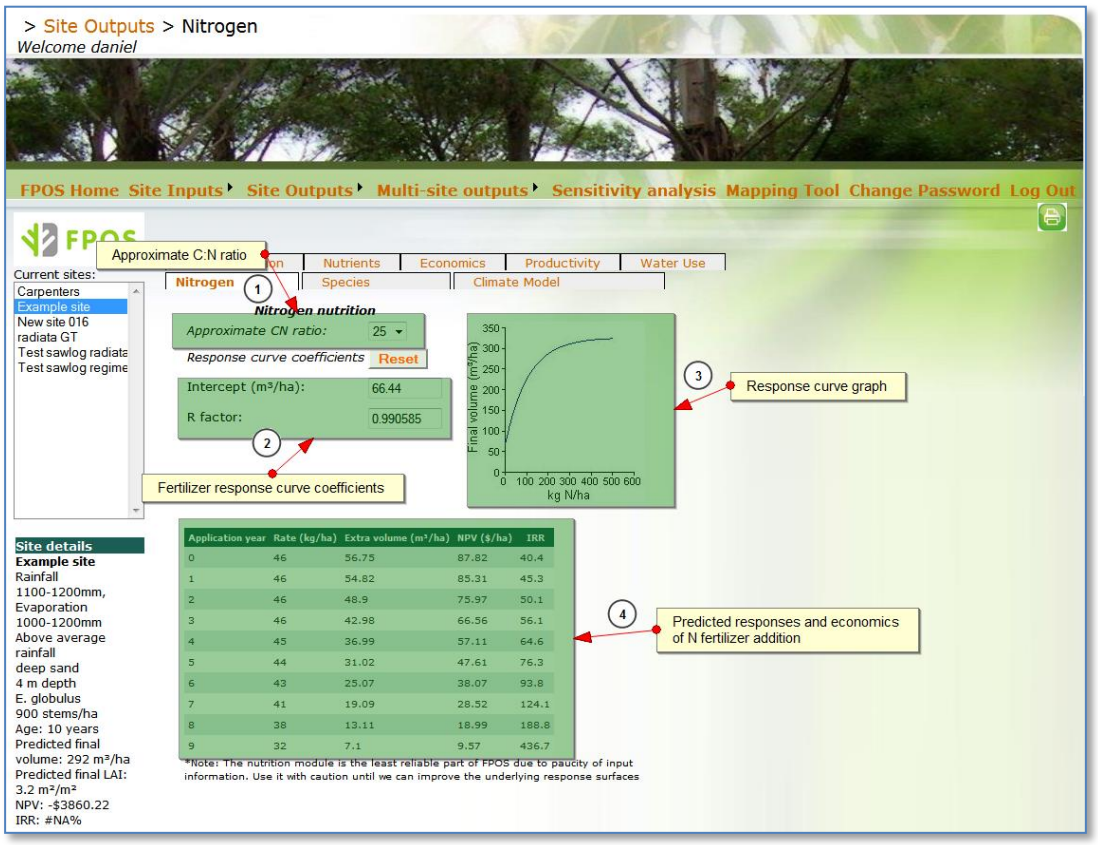
Fig. 15 – Water use efficiency tab, highlighting (1) the current and comparison scenarios, (2) the button to run CABALA for missing data, (3) and (4) the water use efficiency output graphs.



Nitrogen

The nitrogen tab is intended to help users make decisions about nitrogen fertilizer management. This module is relatively weak and not intended to replace more complex tools such as NPOpt for *P. radiata* in the Green Triangle, rather it is intended to give users a feel for the economics of N fertilizer addition. The first step is to characterise the shape of the response curve (Item 3, Fig. 16). For *E. globulus* this may be achieved by adjusting the approximate C:N ratio of the top 10 cm of soil (Item 1, Fig. 16). For other species this is not likely to be very accurate, so the user needs to enter their own intercept and curvature (R) factor into the input boxes (Item 2, Fig. 16). The output (Item 4, Fig. 16) calculates the optimal rate of N fertilizer to maximise NPV for the fertilizer application. The calculations assume that fertilizer is applied in only one of the 'application years', and estimates the additional volume that may be achieved by application in that year.

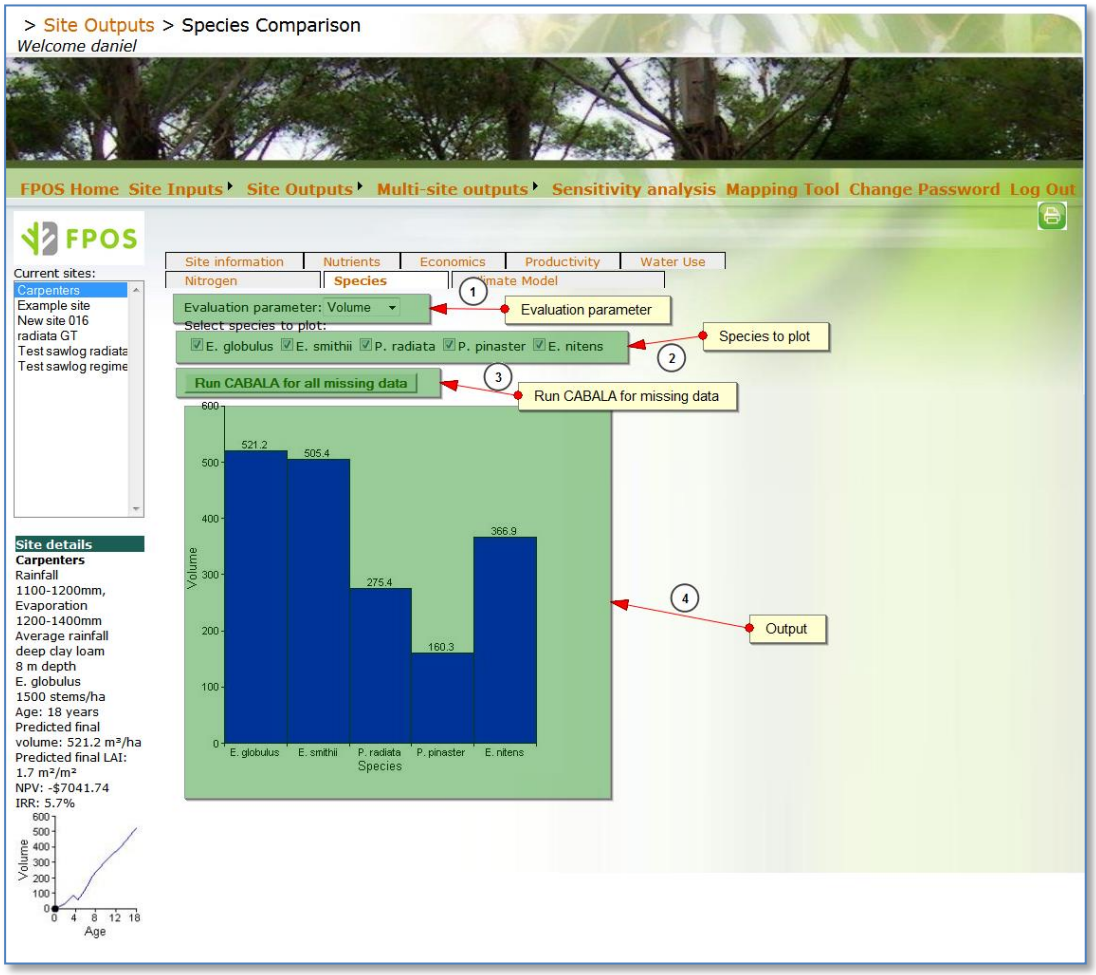
Fig. 16 – Nitrogen fertilizer tab, highlighting (1) the C:N ratio input box, (2) the fertilizer response curve coefficients, (3) the response curve shown graphically, and (4) the output from the module.


> Site Outputs > Nitrogen
Welcome daniel
FPOS Home Site Inputs Site Outputs Multi-site outputs Sensitivity analysis Mapping Tool Change Password Log Out
Approximate C:N ratio
Nutrients Economics Productivity Water Use
Nitrogen Species Climate Model
1
Nitrogen nutrition
Approximate CN ratio: 25
Response curve coefficients Reset
Intercept (m³/ha): 66.44
R factor: 0.990585
2
Fertilizer response curve coefficients
Final volume (m³/ha)
kg N/ha
3
Response curve graph
Current sites:
Carpenters
Example site
New site 016
radiata GT
Test sawlog radiata
Test sawlog regime
Site details
Example site
Rainfall 1100-1200mm,
Evaporation 1000-1200mm
Above average rainfall
deep sand
4 m depth
E. globulus
900 stems/ha
Age: 10 years
Predicted final volume: 292 m³/ha
Predicted final LAI: 3.2 m²/m²
NPV: -$3860.22
IRR: #NA%
Application year Rate (kg/ha) Extra volume (m³/ha) NPV ($/ha) IRR
0 46 56.75 87.82 40.4
1 46 54.82 85.31 45.3
2 46 48.9 75.97 50.1
3 46 42.98 66.56 56.1
4 45 36.99 57.11 64.6
5 44 31.02 47.61 76.3
6 43 25.07 38.07 93.8
7 41 19.09 28.52 124.1
8 38 13.11 18.99 188.8
9 32 7.1 9.57 436.7
4
Predicted responses and economics of N fertilizer addition
*Note: The nutrition module is the least reliable part of FPOS due to paucity of input information. Use it with caution until we can improve the underlying response surfaces

Species Comparison

The species comparison tab allows the user to compare the model outputs for some or all of the 5 species that are currently in the system. The evaluation parameter (Item 1, Fig. 17) allows the user to explore the predicted volume, height, diameter, leaf area index, water use efficiency, IRR or NPV. All 5 of the species can be compared, or a subset of the most relevant species can be compared by checking/unchecking the individual species (Item 2, Fig. 17). If the relevant CABALA runs do not exist in the database, the user can choose to run CABALA for the missing scenarios by clicking 'Run CABALA' (Item 3, Fig. 17).

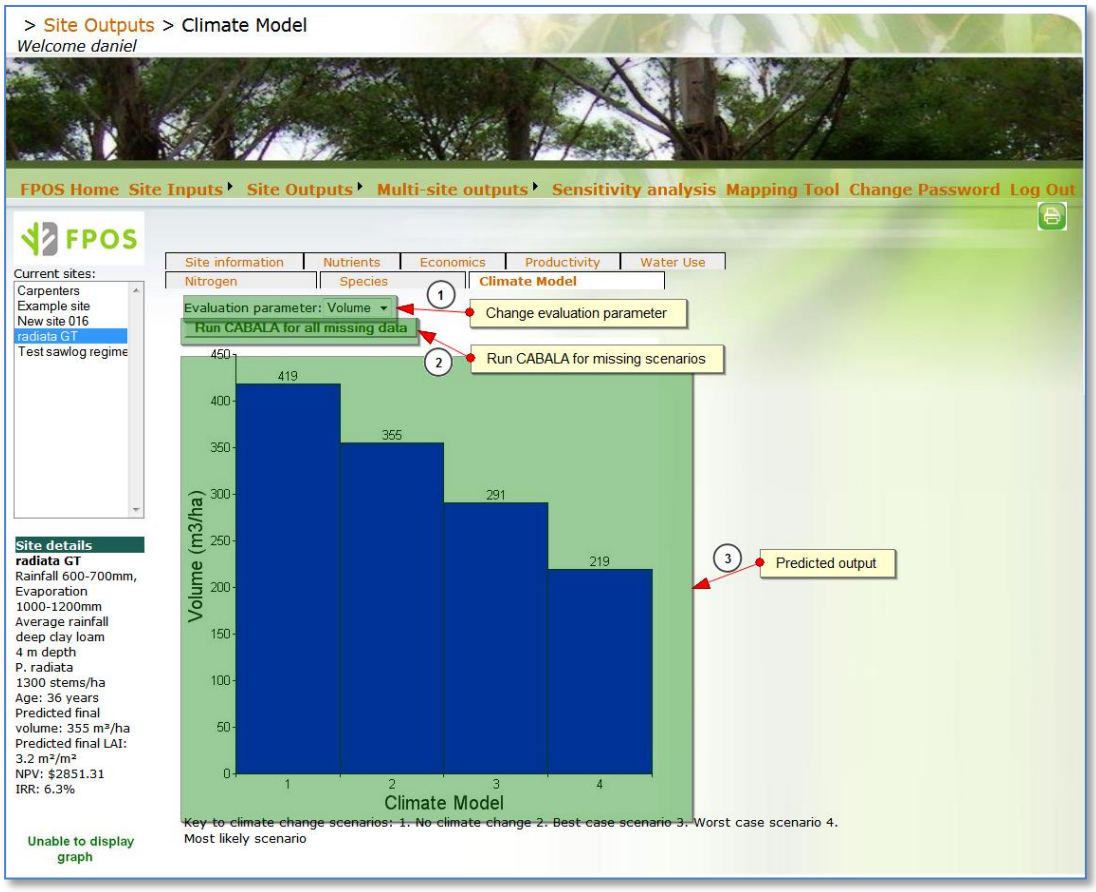
Fig. 17 – Species comparison tab, with the (1) evaluation parameter, (2) species selection, (3) 'run CABALA' button, and (4) output graph highlighted



Climate model

The climate model tab allows the user to explore the impact of different projected climate models on the predicted productivity and economics

Fig. 18 – Climate model comparison tab, with the (1) evaluation parameter selection, (2) Run CABALA button, and (3) model output highlighted.



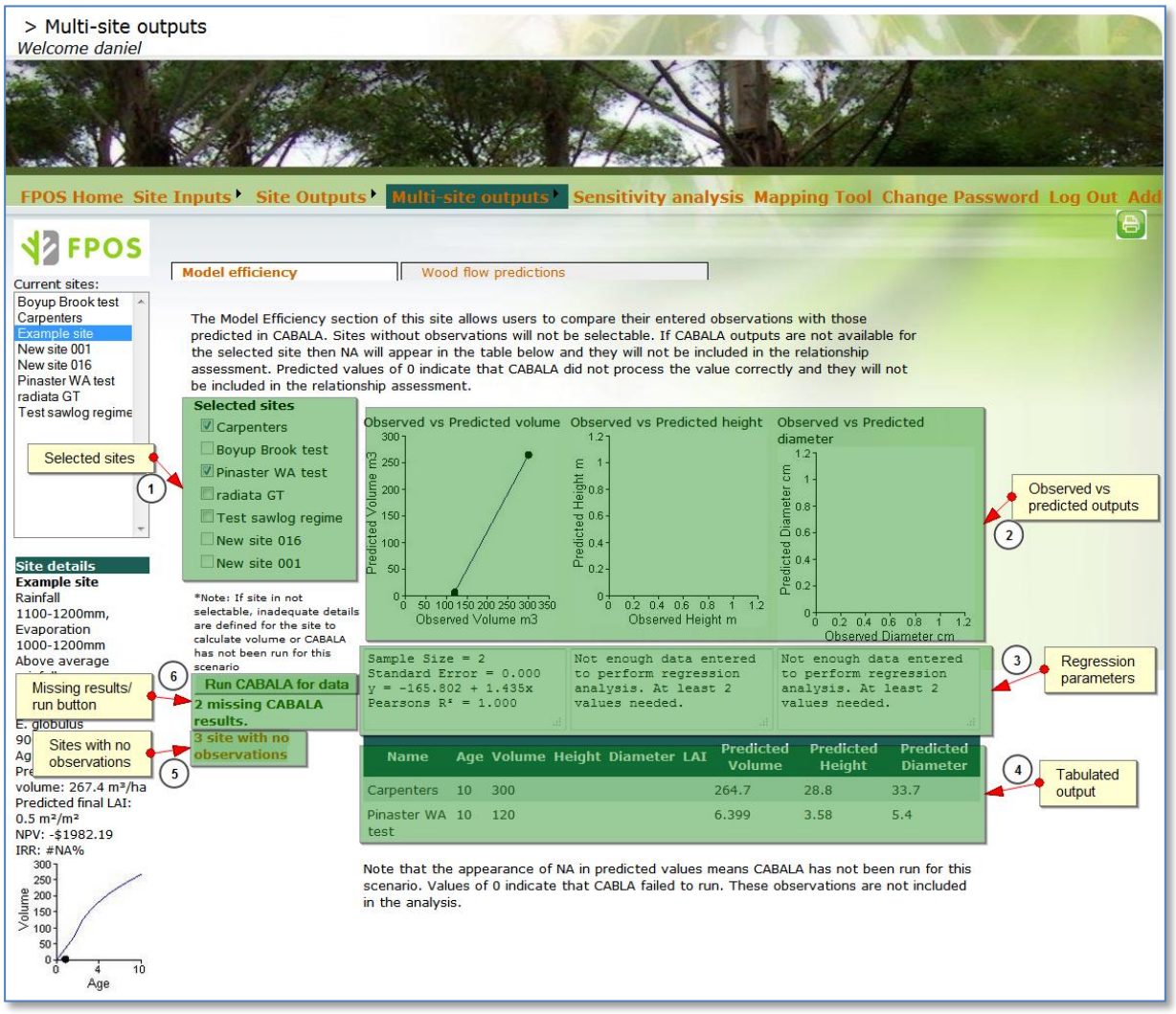
Multi-site Outputs

Multi-site outputs allow the user to explore the model efficiency and predicted wood flow across their range of sites.

Model efficiency

The model efficiency tab shows a graph of observed vs predicted productivity, height and/or diameter. This is an opportunity for the user to compare how well the system is predicting productivity across their sites that are entered into the system. The user can choose which sites to present in the output by selecting from the list (Item 1, Fig. 19). Note that the system can only show sites where observed data has been entered by the user (see Fig. 9 above), and where CABALA has been run. The system will not allow you to select sites where either of these criteria have not been met. It gives a warning about the number of sites that don't have data (Item 5, Fig. 19), and the number of sites that don't have CABALA runs available (Item 6, Fig. 19). The user can choose to run the missing sites by clicking on the 'run CABALA' button (Item 6, Fig. 19). The outputs of the observed vs predicted productivity are shown in graphical (Item 2, Fig. 19) and tabular (Item 4, Fig. 19) form, and regressions are fitted to the data (Item 3, Fig. 19) to describe the goodness of fit between observed and predicted values.

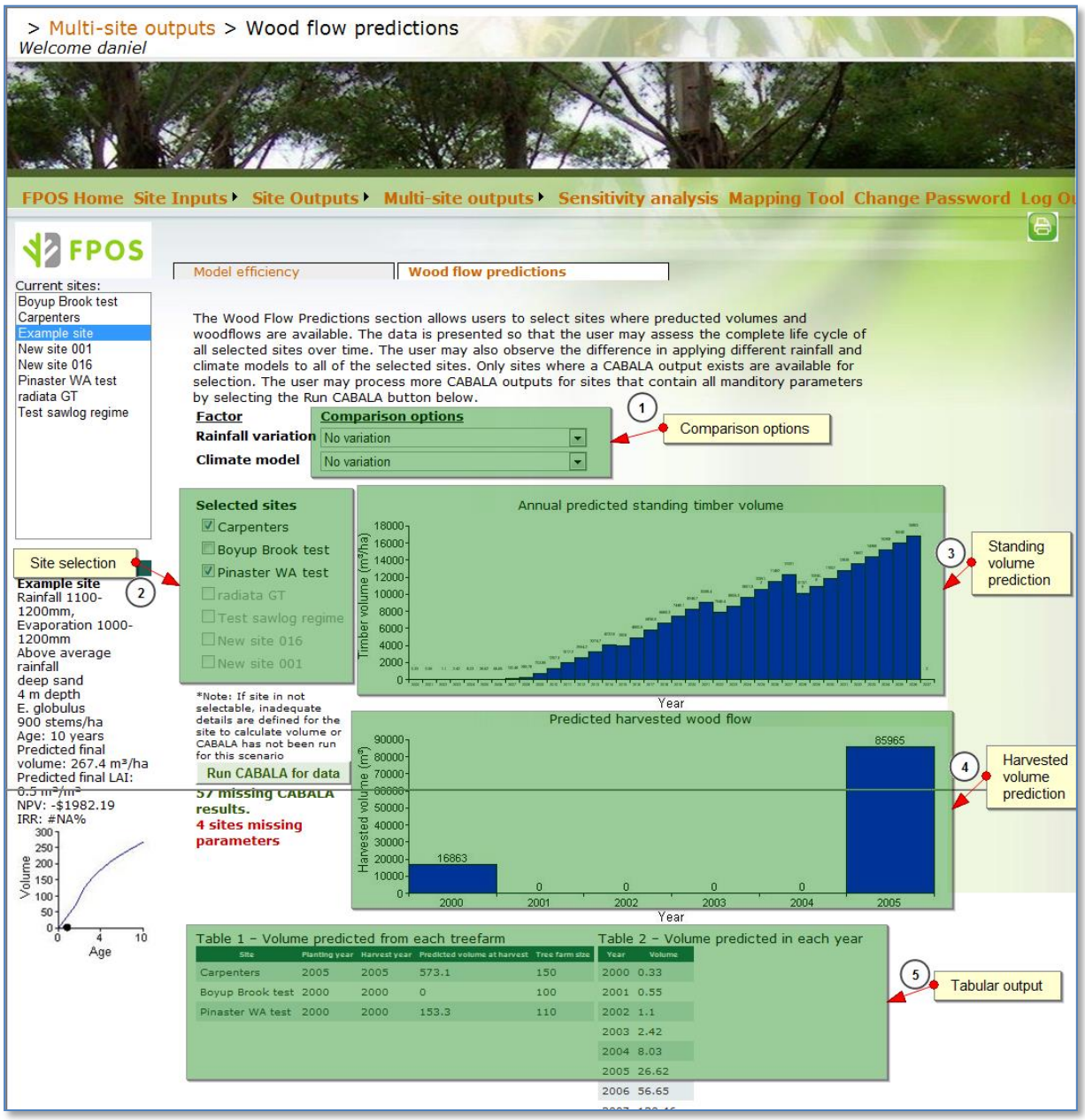
Fig. 19 – Model efficiency tab, showing (1) the site selection panel, (2) the observed and predicted outputs in graphical form, (3) regression outputs, (4) the tabulated output of observed vs predicted output, (5) the number of sites without observed data, and (6) the number of sites without CABALA outputs.


> Multi-site outputs
Welcome daniel
FPOS Home Site Inputs Site Outputs Multi-site outputs Sensitivity analysis Mapping Tool Change Password Log Out Add
FPOS
Current sites:
Boyup Brook test
Carpenters
Example site
New site 001
New site 016
Pinaster WA test
radiata GT
Test sawlog regime
Model efficiency
Wood flow predictions
The Model Efficiency section of this site allows users to compare their entered observations with those predicted in CABALA. Sites without observations will not be selectable. If CABALA outputs are not available for the selected site then NA will appear in the table below and they will not be included in the relationship assessment. Predicted values of 0 indicate that CABALA did not process the value correctly and they will not be included in the relationship assessment.
Selected sites
Carpenters
Boyup Brook test
Pinaster WA test
radiata GT
Test sawlog regime
New site 016
New site 001
Selected sites
1
*Note: If site in not selectable, inadequate details are defined for the site to calculate volume or CABALA has not been run for this scenario
Observed vs Predicted volume
Predicted Volume m3
Observed Volume m3
Observed vs Predicted height
Predicted Height m
Observed Height m
Observed vs Predicted diameter
Predicted Diameter cm
Observed Diameter cm
Observed vs predicted outputs
2
Site details
Example site
Rainfall 1100-1200mm,
Evaporation 1000-1200mm
Above average
Missing results/ run button
6
Run CABALA for data
2 missing CABALA results.
Sites with no observations
5
3 site with no observations
Sample Size = 2
Standard Error = 0.000
y = -165.802 + 1.435x
Pearsons R² = 1.000
Not enough data entered to perform regression analysis. At least 2 values needed.
Not enough data entered to perform regression analysis. At least 2 values needed.
3
Regression parameters
Name Age Volume Height Diameter LAI Predicted Volume Predicted Height Predicted Diameter
Carpenters 10 300 264.7 28.8 33.7
Pinaster WA test 10 120 6.399 3.58 5.4
4
Tabulated output
volume: 267.4 m³/ha
Predicted final LAI:
0.5 m²/m²
NPV: -$1982.19
IRR: #NA%
Volume
Age
Note that the appearance of NA in predicted values means CABALA has not been run for this scenario. Values of 0 indicate that CABLA failed to run. These observations are not included in the analysis.

Wood flow predictions

The wood flow predictions allow the user to explore the potential impact of rainfall variation and/or alternative climate model on the predictions of long-term standing volume and harvested wood volumes. The user can vary comparison options independently for rainfall variation and for climate model (Item 1, Fig. 20), with the predicted output shown graphically for standing volume (Item 3, Fig. 20), and harvest volumes (Item 4, Fig. 20). The sites that are included in the output are selected individually through the check-boxes (Item 2, Fig. 20)

Fig. 20 – Wood flow predictions tab, highlighting (1) the pull-down comparison options, (2) site selection, (3) graphical output of standing volume prediction, (4) graphical output of harvest volumes, and (5) tabular output of standing volume and harvested volumes.

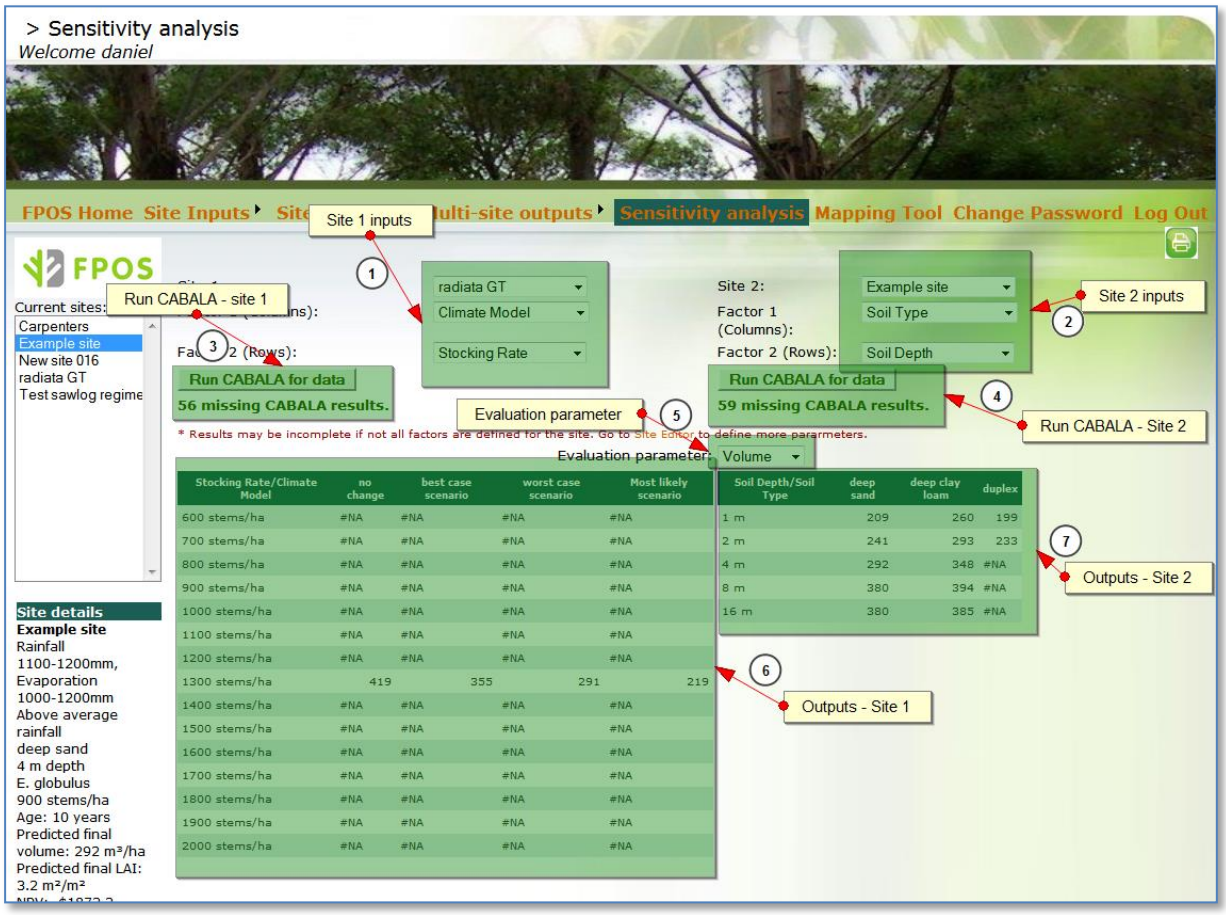

> Multi-site outputs > Wood flow predictions
Welcome daniel
FPOS Home Site Inputs Site Outputs Multi-site outputs Sensitivity analysis Mapping Tool Change Password Log O
FPOS
Model efficiency
Wood flow predictions
Current sites:
Boyup Brook test
Carpenters
Example site
New site 001
New site 016
Pinaster WA test
radiata GT
Test sawlog regime
The Wood Flow Predictions section allows users to select sites where predicted volumes and woodflows are available. The data is presented so that the user may assess the complete life cycle of all selected sites over time. The user may also observe the difference in applying different rainfall and climate models to all of the selected sites. Only sites where a CABALA output exists are available for selection. The user may process more CABALA outputs for sites that contain all manditory parameters by selecting the Run CABALA button below.
Factor
Comparison options
Rainfall variation
No variation
Climate model
No variation
1
Comparison options
Selected sites
Carpenters
Boyup Brook test
Pinaster WA test
radiata GT
Test sawlog regime
New site 016
New site 001
Site selection
2
Example site
Rainfall 1100-1200mm,
Evaporation 1000-1200mm
Above average rainfall
deep sand
4 m depth
E. globulus
900 stems/ha
Age: 10 years
Predicted final volume: 267.4 m³/ha
Predicted final LAI: 0.5 m²/m²
NPV: -$1982.19
IRR: #NA%
Volume
Age
*Note: If site in not selectable, inadequate details are defined for the site to calculate volume or CABALA has not been run for this scenario
Run CABALA for data
57 missing CABALA results.
4 sites missing parameters
Annual predicted standing timber volume
Timber volume (m³/ha)
Year
3
Standing volume prediction
Predicted harvested wood flow
Harvested volume (m³)
16863
85965
Year
4
Harvested volume prediction
Table 1 – Volume predicted from each treefarm
Site
Planting year
Harvest year
Predicted volume at harvest
Tree farm size
Carpenters 2005 2005 573.1 150
Boyup Brook test 2000 2000 0 100
Pinaster WA test 2000 2000 153.3 110
Table 2 – Volume predicted in each year
Year
Volume
2000 0.33
2001 0.55
2002 1.1
2003 2.42
2004 8.03
2005 26.62
2006 56.65
5
Tabular output

Sensitivity Analysis

The sensitivity analysis tool allows the user to explore model predictions in a matrix-style output for the factor levels that are available in the system. For example, a combination of soil type and soil depth for a given site presents all of the CABALA predictions for each combination of soil type and soil depth (in this example, a total of 15 scenarios). The page gives the user the option to compare 2 output matrices/tables alongside each other. A site needs to be selected as the base scenario for each table, and then the row and column factors to explore need to be selected (Items 1 and 2, Fig. 21). As this analysis draws output from many individual CABALA runs, it is likely that there may not be all of the runs in the database, at least initially, so the interface will tell the user how many CABALA scenarios need to be run, and the user can start these by clicking 'Run CABALA' (Items 3 and 4, Fig. 21). Note that a typical CABALA run takes around 1 minute, so if there are 60 missing scenarios, it may take around 1 hour to complete (depending on server load). Once the

scenarios are completed and in the output database, then they are available for the next time the same query is run, or if a different query is run that uses some or all of those outputs.

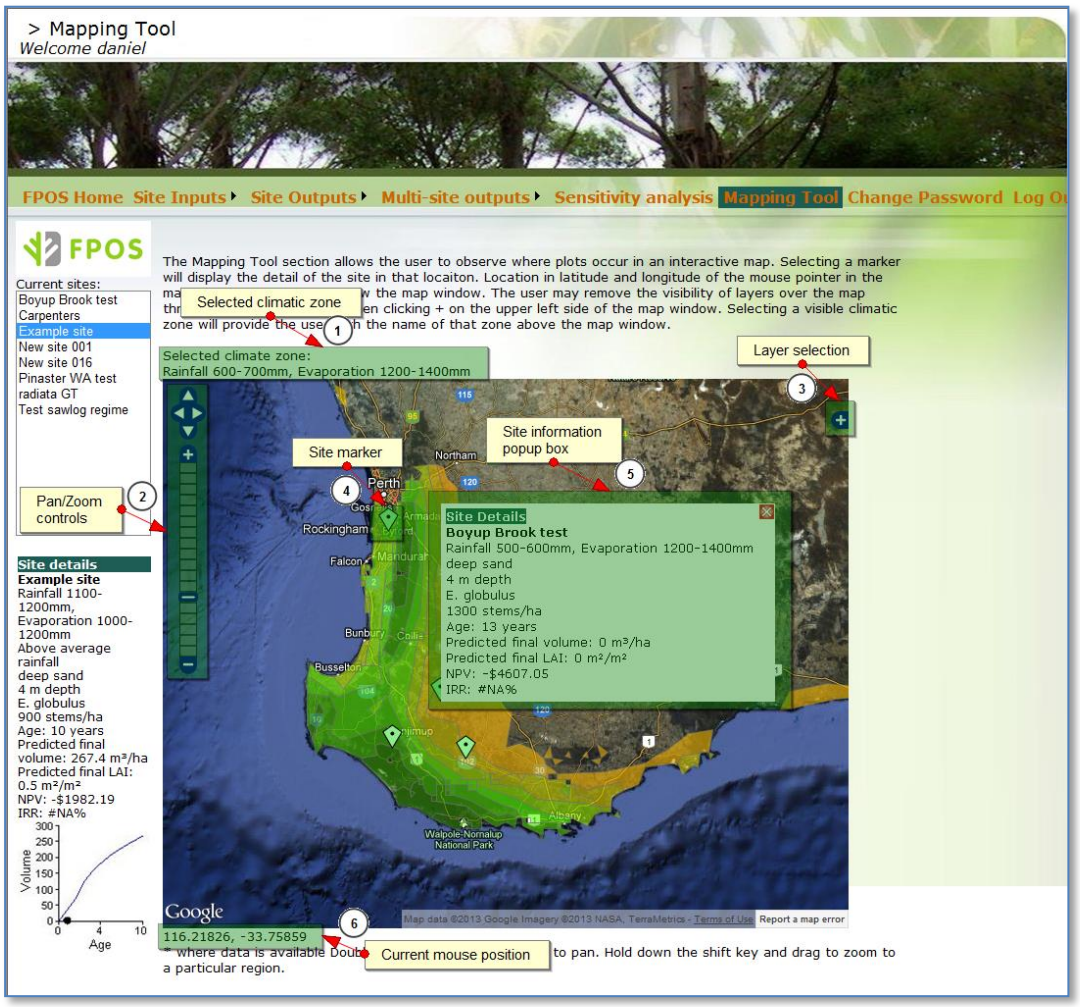
Fig. 21 – Sensitivity analysis tab, highlighting (1 and 2) Inputs for comparison sites 1 and 2, (3 and 4) button to run CABALA for scenarios that are not yet in the database, (5) the evaluation parameter, and (6 and 7) the output tables.



Mapping tool

The mapping tool allows users to view the location of their sites, and view summaries of the outputs for each site. The FPOS climatic zones are also shown so that the most appropriate climatic zone can be chosen. The maps are derived from Google Maps™, so the user can zoom in to treefarm (or sub-treefarm) level in most cases. Zooming and panning can be done directly with the mouse (and scroll-wheel), or with the map controls (Item 2, Fig. 22) The climatic zones and/or sites can be shown on, or removed from, the map by selecting the appropriate layers from the layer selection menu (Item 3, Fig. 22). The site locations are indicated with green diamonds (Item 4, Fig. 22), which if clicked on, will result in a pop-up site information box (Item 5, Fig. 22), which includes some of the inputs and some of the outputs for the selected site. A climatic zone can be highlighted by clicking on it, and the name will appear at the top of the map (Item 1, Fig. 22). The coordinates of the point under the mouse cursor can be viewed at the bottom of the screen (Item 6, Fig. 22), which can be used as a guide for entering into the site-information section (Fig. 8). Note that this is not yet automatic, but we may be able to include this feature in the future.

Fig. 22 – The mapping tool page, highlighting (1) the currently selected climatic zone, (2) the pan/zoom controls, (3) the layer selection, (4) an example site marker, (5) the site information popup box, and (6) the current mouse position.



FPOS limitations

FPOS is not a perfect tool, and will not always give the right result. Key limitations include the following:

- One of the key strengths of FPOS is also one of its weaknesses, which is that it relies upon CABALA as the underlying engine to predict productivity. CABALA is useful for conducting 'what-if' type analyses, but can also provide counter-intuitive or perverse results under some scenarios or combinations of inputs. Thus, the output must always be considered in this context. CABALA is under continual improvement and identification of sites and situations where CABALA doesn't appear to work well are welcome for further investigation.
- The climate models embedded into the system are necessarily a simplification of the actual model output, with the primary limitation being that FPOS uses average monthly data, so it cannot replicate the extreme events. For example, it does not model drought climatic sequences per se (only reduced rainfall by user choice), or changes in frost frequency.
- FPOS does not attempt to deal with some factors that can have a significant impact on plantation productivity – these include pests, disease, weeds, micronutrients and most macronutrients (other than through the generic 'fertility' ranking). Other tools are

more suitable to assess these effects and/or more research is required to allow them to be embedded into FPOS.

- Coppice productivity may be over-predicted, due to a lack of knowledge about coppice physiology post-reduction. Currently CABALA assumes that the coppice trees have the same shape and response to environment as seedling trees after they are reduced to 1 or 2 stems. Note that FPOS models coppice reduction down to 1 stem per stool at age 2.
- The calculation of log sizes from the predicted tree-size distribution relies on a conical approximation to calculate the lengths of logs in each of the log size categories (pro-rated back to the calculated volume), but trees grown for sawlogs typically have less of a taper in the clear section of the bole, so the conical function will probably tend to underestimate the quantities of larger logs and over-estimate the quantities of smaller logs.
- Nutrient export calculations are based on allometrics for biomass of different tree components and standard tissue concentrations for nutrients. The best characterised species are *E. globulus* and *P. radiata*, so the outputs for these species are likely to be reasonable, but the other species are not as well characterised so may not be as accurate in their predictions.

References

Hopmans and Elms (2009). Changes in total carbon and nutrients in soil profiles and accumulation in biomass after a 30-year rotation of *Pinus radiata* on podsolised sands: